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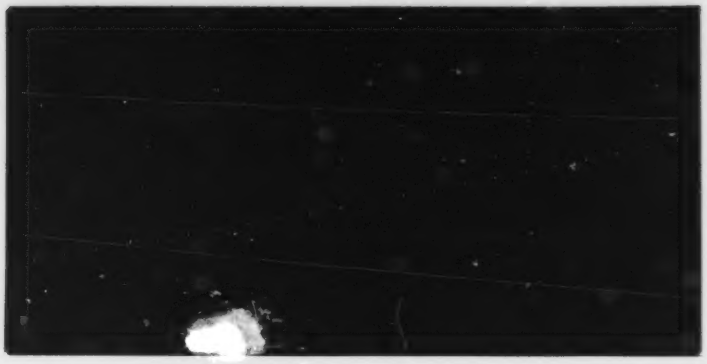

Energy, Mines and Resources Canada

Énergie, Mines et Ressources Canada

ASSESSMENT OF THE NEED FOR NEW CONTROLS FOR SOLAR BUILDINGS

RENEWABLE ENERGY BRANCH

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Preface

The intended purpose of this report is to review the present uses of controls in solar design and to suggest what types of controllers may be most appropriate in the future. The report should be useful to persons working in solar design as an overview and as a guideline for future research and development work. A survey of controller products on the market is intended to give a sample of what is available although some products may have been inadvertently omitted. The report does not endorse any specific commercial product. The report draws together previous work on solar controllers and expands on that work to include passive solar design and ideas about potential development of controllers for the solar building industry.

Abstract

The use of controllers for solar buildings is assessed in the context of existing control strategies and present trends in solar building design. The objective of the work is to outline the current state of the art in controllers for solar buildings and to suggest requirements for future controllers that could be developed to optimize energy use and comfort in solar buildings.

Data for the report was drawn from a survey of representatives of the solar building industry, a survey of controls manufacturers, and in-house research on microprocessor controller technology. The findings indicate that there is an increasing emphasis on solar building design that combines several energy strategies. Occupant comfort is also an important issue for control systems. Programmable controllers, which can manage aspects of the building such as daylighting in addition to heating and cooling, are advantageous for many buildings but their use is hampered by problems in the available technology with reliability, limited control logic, and user interface.

Requirements for new controllers for solar buildings are suggested: controllers should be flexible enough to control a variety of systems and use advanced control algorithms to provide the necessary precision. Human factors are a key issue and it is important for people in the design field of the solar industry to become more knowledgeable about control systems and for controllers to be more "user friendly."

The project provides a current view of controls for solar buildings. The technology is rapidly changing and at present a combination of more accessible information and improved controllers promises significant increases in energy efficiency and comfort in solar buildings.

Résumé

Les contrôleurs destinés aux bâtiments solaires sont examinés en regard des stratégies de contrôle actuelles et des tendances des concepteurs de ces bâtiments. L'objectif poursuivi est de décrire la situation actuelle de la technologie des dispositifs de contrôle et de proposer des critères pour la réalisation de contrôleurs destinés à optimiser l'utilisation de l'énergie et favoriser le confort dans ces bâtiments.

Les données utilisées dans le présent rapport proviennent d'une enquête effectuée auprès de représentants de l'industrie du bâtiment solaire, de fabricants de contrôleurs et de chercheurs fédéraux affectés à la technologie des contrôleurs dotés d'un microprocesseur. L'enquête révèle une tendance croissante à conjuguer plusieurs stratégies énergétiques dans la conception des bâtiments solaires. Les concepteurs des systèmes de contrôle doivent également accorder de l'importance au confort des occupants. Les contrôleurs programmables, qui règlent l'éclairage naturel, le chauffage et le refroidissement, sont avantageux dans le cas de nombreux bâtiments, mais il reste à résoudre des problèmes technologiques pour que ces dispositifs soient fiables, de contrôle logique et d'utilisation facile.

Des critères sont proposés pour la conception des nouveaux contrôleurs. Ils devraient être suffisamment souples pour régler un éventail de systèmes, et utiliser des algorythmes avancés essentiels à la précision voulue. Les facteurs humains sont déterminant, aussi importe-t-il que les concepteurs de matériel solaire approfondissent leur connaissance des systèmes de contrôle et que les contrôleurs deviennent plus faciles à utiliser.

Le projet donne un aperçu de la situation actuelle des contrôleurs destinés aux bâtiments solaires. La technologie évolue rapidement et il est permis de croire que les nouvelles connaissances et les contrôleurs améliorés permettront vraisemblablement de hausser de beaucoup le rendement énergétique des bâtiments et leur confort.

Table of Contents

	List of Figures	v
	Executive Summary	vi
	Resume	ix
1.0	INTRODUCTION	1
2.0	OBJECTIVES AND METHODOLOGY	2
3.0	RESEARCH ON CONTROLLING SOLAR ENERGY COLLECTION SYSTEMS	3
	3.1 General Strategies for Temperature Control in Solar Buildings	3
	3.2 Solar Building Systems	7
	3.3 Active Solar Energy Systems	9
	3.4 Computer Simulations	11
	3.5 Advanced Controllers Developed	12
	3.6 General Trends in Controller Applications and Requirements	13
	3.7 The Building Industry and Solar Controls	16
4.0	TECHNICAL & ECONOMIC ISSUES FOR SOLAR CONTROLS IN THE CANADIAN CONTEXT	26
	4.1 Introduction	26
	4.2 Sensors	30
	4.3 Actuators	31
	4.4 Signal Transmission	31
	4.5 Controller	32
	4.6 Human Factors	34
	4.7 Whole Systems	36
5.0	CONCLUSIONS & RECOMMENDATIONS	38
	REFERENCES	42
	APPENDICES	
	A - The Building Industry - Survey	46
	B - Controller Products	50

List of Figures

Figure 3.1 Occupation 17
Figure 3.2 Type of Systems/Buildings 18
Figure 3.3 Type Systems/Buildings 18
Figure 3.4 Building Types 19
Figure 3.5 Controllers Adequate for Needs? 19
Figure 3.6 Shortcomings of Existing Controllers 20
Figure 3.7 Situations Automatic Controls Preferable to Manual Controls 21
Figure 3.8 Features Most Important 22
Figure 3.9 User Programming 22
Figure 3.10 Information Source 23
Figure 3.11 Growth 23

Figure 4.1 Environmental Control - A Systems Viewpoint 26
Figure 4.2 Relation of User and Zone Control 28
Figure 4.3 Controller System Design - Life Cycle 29
Figure 4.4 Residential vs. Commercial Building Control Issues 35

Figure 5.1 Control Requirements-Choice-Consequences 39

EXECUTIVE SUMMARY

The field of controls has been largely neglected in past research on the design and performance of solar energy systems. With the present trend toward incorporation of solar in commercial buildings and the design of hybrid systems including various types of solar and conventional systems, there is a growing need for sophisticated control systems which are capable of controlling solar buildings. This report investigates the present and future needs for controllers in the existing Canadian solar building industry.

The work was done by collecting information on existing controllers from manufacturers; a telephone survey of solar designers, engineers, manufacturers, distributers and installers; and a survey of the technical literature on present trends in solar design and control systems. Technical recommendations also draw on previous in-house research on microprocessor controllers.

Controls for solar buildings range from the simple (open a window) to the complex (large commerical buildings with no operable windows). Different types of controls are needed to satisfy these diverse markets. A recurring problem in passive solar buildings is that occupants, particularly second occupants, do not adequately operate manual controls. In addition, many solar buildings are now hybrid systems which frequently require more elaborate control. Many designs now include a variety of passive solar features as well as active hybrid systems with fans, thermostats, and thermal storage. Representatives of the solar industry concurred that automatic controllers are generally preferable unless the manual controls are extremely simple.

The survey of representatives of the solar building industry indicated that less than half of the respondents were satisfied with presently manufactured controllers. Their comments emphasized that simple thermostats are frequently used because it is difficult to get components to work together and because many people do not know much about controllers and rely on suppliers for their information.

Controllers for active solar systems such as pools appear to be adequate except for the problem of sensor and system reliability and the possible need for controllers suited to low flow solar domestic hot water systems. The area of greatest need in controller research is in integrated solar and conventional systems.

Advances in microprocessor technology have facilitated the development of sophisticated controllers which can implement different control strategies, what is controlled and when, in buildings. Conventional control strategies rely largely on maintaining room temperature with a thermostatically controlled heater or fan. In recent years there has been an increased emphasis on thermal and visual comfort of occupants and strategies for daylighting and thermal storage in solar buildings.

Microprocessor-based programmable controllers are being used to control integrated systems. One problem is that the available controllers are not designed specifically to be used with solar features and many do not have the flexibility necessary for optimal control. Research on suitable algorithms is clearly an area where further work is needed. Computer simulations and work on advanced controllers indicate that thermal performance and comfort in solar buildings can be improved when local climate, building type, and occupancy can be taken into account in the control algorithms.

Automatic controls need to be considered from a systems viewpoint (e.g. consisting of sensors, controller, actuators). Any weakness in any one component effects the whole system. Therefore attention needs to be placed not only on the individual components but the whole system operation.

A variety of systems are in use controlling single, multiple, and centrally controlled multiple zone systems. The life cycle of the control system needs to be considered particularly in consideration of a second generation user.

The central controller is the "brains" of the control system. Designers usually pointed to the controller as the source of control problems. Controllers can be made "smarter" to monitor the installation and check out of the control system, warn the user if there is a system failure or inappropriate control algorithm selected, and provide more information to the user for system performance checks and diagnosis. The central control system could use adaptive control algorithms to be more responsive to changes in the weather and user occupancy patterns.

User friendliness has been often neglected in controls design in favour of low cost electronics and limitations due to controller memory and microprocessor power. With more powerful microprocessors and additional inexpensive memory it is now possible to put more "intelligence" into the controller making it easier to use. Survey respondents affirmed that many available controllers are confusing to the operator. A manual override is desirable, however, the majority of respondents thought that the user should not be able to readily program a controller other than for simple set points. User friendliness, ease of installation and ease of maintenance were recurring issues noted by respondents. Increased control sophistication thus must be combined with increased simplicity for the end user.

There are a number of non-technical issues that influence the direction of building control. Usually the designer, supplier, builder, and occupant, are all trying to optimize the control of the building but with different goals and assumptions. For residential buildings low cost control solutions are usually indicated often sacrificing comfort and energy savings. Users in commercial buildings usually have little control of their space with control of the building shifted to a building operator and/or owner. Central HVAC systems allow little variation in

climate control since many user occupied zones are controlled by a central thermostat (programmed by the building operator not the user). New fault-free and easy to use systems are needed that can satisfy occupants, operators, and owners of buildings.

Some specific recommendations on controls from the user perspective include: the development of a simple decision-making tool to assist in control design and selection, simplier to understand and program central controllers, and less expensive but reliable control options. Technology transfer is needed in the form of written material and training for the controls industry and for the end user (first and secondary user).

The solar industry has matured and is merging with the general building industry. What is now needed are controllers with solar features, instead of solar controllers, that can also control a conventional building. Controllers need to integrate with standard HVAC equipment and be configurable for the many different types of systems in use. Work is not only needed in producing more reliable sensors, actuators, and central controls but also work is needed in control algorithm development and control systems with open architecture capable of sharing software.

The work reported herein is intended to summarize the state of the art in solar controllers and suggest directions for future work. It is a timely report since the future of solar depends more on making present building solar systems perform efficiently and reliably than on the development of new systems. Controls are the key to efficiency and occupant comfort for integrated solar buildings. The report does not include information on all available controllers, but it does provide an overview of the technology. Further work is needed to educate the solar building industry about controls and to develop future controllers which will optimize both energy efficiency and comfort in solar buildings.

Les dispositifs de contrôle ont été fort négligés au cours des recherches qui ont porté jusqu'à maintenant sur la conception et le rendement des systèmes énergétiques solaires. Or, l'installation d'un nombre croissant d'appareils solaires dans les bâtiments commerciaux et la conception de systèmes hybrides intégrant divers types d'appareils solaires et classiques font augmenter les besoins en systèmes de contrôle très évolués qui soient capable de bien régler les installations des bâtiments solaires. Les auteurs du présent rapport examinent les besoins actuels et à venir de l'industrie canadienne du bâtiment solaire en ce qui a trait aux dispositifs de contrôle.

Des fabricants ont été consultés sur les contrôleurs actuels; une enquête téléphonique a été faite auprès des concepteurs, des ingénieurs, des fabricants, des distributeurs et des installateurs de matériel solaire et la documentation technique sur les tendances actuelles de la conception des bâtiments solaires et des systèmes de contrôle a été examinée. Les recommandations techniques s'appuient aussi sur les résultats de recherches internes antérieures sur les contrôleurs dotés d'un microprocesseur.

Les contrôleurs installés dans les bâtiments solaires exécutent des tâches parfois simples (ouvrir une fenêtre), parfois complexes (dans un grand bâtiment commercial à fenêtres fixes).

Divers types de dispositifs de contrôle satisfont à ces divers besoins. Il arrive souvent que les occupants des bâtiments dotés d'installations solaires passives ne savent pas bien utiliser les dispositifs manuels, en particulier, s'ils ont été installés par des occupants antérieurs. Un autre problème est que de nombreux bâtiments comportent maintenant des systèmes hybrides nécessitant des contrôleurs complexes. De nombreux plans d'habitation comprennent aujourd'hui diverses installations solaires passives de divers systèmes hybrides actifs, y compris des

ventilateurs, des thermostats et un stockage thermique. Á ce chapitre, les représentants de l'industrie sont d'avis qu'il est préférable, en général, d'installer des contrôleurs automatiques, à moins que les contrôleurs manuels envisagés ne soient extrêmement simples.

Moins de la moitié des répondants de l'industrie du bâtiment solaire se sont dits satisfaits des dispositifs de contrôle fabriqués actuellement. Ils choisissent fréquemment les thermostats simples, car plus il comportent d'éléments, plus ils fonctionnent difficilement, et parce que de nombreuses personnes n'y connaissent rien et doivent s'en remettre aux explications du fournisseur.

Les contrôleurs des installations solaires passives semblent satisfaisants, à l'exception des problèmes que posent la fiabilité des détecteurs et des installations et la perspective de devoir installer des contrôleurs spécialement conçus pour les chauffe-eau automatiques solaires à faible débit. Ce sont les contrôleurs destinés aux installations intégrées, aussi bien solaires que classiques, qui exigent le plus de recherches supplémentaires.

Les perfectionnements de la technologie des microprocesseurs ont accéléré la réalisation de contrôleurs perfectionnés permettant d'appliquer diverses stratégies de contrôle en déclenchant la mise en marche et l'arrêt des installations aux moments voulus dans les bâtiments. Auparavant, la stratégie se résumait surtout au maintient de la température au moyen d'un appareil de chauffage ou d'un ventilateur relié à un thermostat. Au cours des dernières années, une plus grande importance a été accordée aux aspects thermal et visuel du confort et aux stratégies d'éclairage naturel et de stockage thermique dans les bâtiments solaires.

On utilise aujourd'hui des contrôleurs programmables par microprocesseur pour contrôler les systèmes intégrés. Toutefois, les contrôleurs disponibles actuellement ne sont pas spécialement conçus pour les installations solaires et bon nombre d'entre eux ne parviennent pas à assurer un contrôle optimal. Il faut donc, de toute évidence, poursuivre

les recherches sur les algorythmes. Selon les simulations sur ordinateur et les recherches consacrées à la mise au point de contrôleurs perfectionnés, il est possible d'améliorer le rendement thermal et le confort dans les bâtiments solaires lorsque les algorythmes de contrôle sont déterminés en fonction des conditions climatiques locales, du type de bâtiment et de la nature des occupants.

Il importe que les contrôles automatiques soient conçus en fonction des systèmes (par exemple, les détecteurs et les dispositifs de contrôle et de mise en marche). Toute faiblesse de l'une ou l'autre des composantes perturbe tout le système. Aussi faut-il accorder de l'attention non seulement aux composantes distinctes, mais aussi au fonctionnement de l'ensemble du système.

Diverses méthodes de contrôle sont appliquées, selon qu'il s'agisse d'un seul local, d'une zone composée de plusieurs locaux, ou de zones multiples dont les installations relèvent d'un contrôleur central. La durée des systèmes de contrôle est également un facteur à examiner, notamment en fonction de l'arrivée éventuelle de nouveaux utilisateurs non initiés.

Selon les concepteurs intérrogés, les problèmes de contrôle sont habituellement dûs au contrôleur central, cerveau du système de contrôle. Il est possible d'améliorer ces contrôleurs pour qu'ils surveillent l'installation, vérifient le système de contrôle, préviennent l'utilisateur lorsqu'une panne se déclare ou qu'un algorythme ne convient pas, et procurent plus de renseignements à l'utilisateur sur la vérification du rendement du système et sur le dépistage des défaillances. Le système de contrôle central pourrait obéir à des algorythmes de contrôle polyvalents, capables de s'adapter aux changements climatiques et aux habitudes de divers utilisateurs.

Le choix de composantes électroniques à coût peu élevé, les limites de la mémoire du contrôleur et la faible puissance du microprocesseur contribuent à réduire la facilité d'utilisation des dispositifs de contrôle. Grâce aux microprocesseurs plus puissants et aux mémoires

supplémentaires peu coûteuses, il est désormais possible d'accroître l'"intelligence", donc la facilité d'utilisation, du contrôleur. Des répondants ont déclaré que de nombreux contrôleurs déjà disponibles sur le marché sont déroutants. Il serait donc préférable de pouvoir passer en mode manuel; toutefois, selon la majeure partie des répondants, l'utilisateur ne devrait pas pouvoir programmer le contrôleur, mais se contenter de modes de fonctionnement préréglés. Les répondants ont souvent soulevé les questions de la facilité d'utilisation, d'installation et d'entretien. Il faut donc non seulement perfectionner les dispositifs de contrôle, mais aussi simplifier leur utilisation.

Un certain nombre de facteurs non techniques influent également sur les décisions que le concepteur, le fournisseur, le fabricant et l'occupant prennent afin d'optimiser le contrôle des installations du bâtiment. Or, des personnes ne partagent pas les mêmes buts et les mêmes suppositions. Dans le cas des bâtiments résidentiels, les solutions à prix modique sont habituellement adoptées aux dépends du confort et des économies d'énergie; dans le cas des bâtiments commerciaux, les utilisateurs n'ont pratiquement pas accès aux réglages, qui sont contrôlés par l'exploitant et (ou) le propriétaire du bâtiment; dans les bâtiments dotés d'un système de contrôle central de la température, de la ventilation et de la climatisation, la température à l'intérieur de bon nombre des locaux est contrôlée par un thermostat central (programmé par l'exploitant du bâtiment) n'autorisant pratiquement aucune variation. De nouveaux systèmes plus simples et à l'épreuve des pannes sont donc nécessaires à la satisfaction des besoins des occupants, de l'exploitant et du propriétaire du bâtiment.

Parmi les recommandations formulées dans l'intérêt des utilisateurs figurent la préparation d'un guide pour 1) aider à la conception et à la sélection des dispositifs de contrôle, 2) simplifier l'utilisation et la programmation des contrôleurs centraux et 3) choisir des modes de contrôle moins coûteux et plus fiables. Des documents d'information et des séances de formation sont nécessaires pour transférer la technologie à l'industrie des dispositifs de contrôle et aux utilisateurs (les premiers propriétaires ainsi que les suivants).

L'industrie solaire a mûri et elle est en voie de s'intégrer à l'industrie du bâtiment, en général. Il faut désormais acquérir, non pas des contrôleurs solaires, mais bien des contrôleurs comportant des composantes solaires et pouvant commander les réglages voulus dans un bâtiment ordinaire. Il importe que les contrôleurs puissent être ajoutés aux installations ordinaires de contrôle de la température, de la ventilation et de la climatisation et soient compatibles avec les nombreux types de systèmes utilisés. Il faut donc poursuivre les recherches pour concevoir non seulement des détecteurs de variation de température etc., des dispositifs de mise en marche et des contrôles centraux plus fiables, mais aussi des algorythmes et des systèmes de contrôle autorisant un partage de logiciel.

Les auteurs du rapport donnent un aperçu de la situation des contrôleurs solaires et proposent des orientations pour les travaux à venir. C'est un rapport bien à-propos, car l'avenir de l'industrie solaire dépend davantage de l'amélioration du rendement et de la fiabilité des installations de ce genre. Les dispositifs de contrôle constituent la clé du rendement des installations solaires et du confort dans les bâtiments solaires intégrés. Les auteurs ne renseignent pas sur tous les contrôleurs disponibles, mais ils procurent un aperçu de la technologie. Il faut faire plus pour renseigner l'industrie du bâtiment solaire sur les dispositifs de contrôle et pour mettre au point des contrôleurs destinés à optimiser le rendement énergétique des bâtiments solaires et à accroître le confort dans ces bâtiments.

1.0 INTRODUCTION

The use of all energy sources has through the ages required some form of "control" by the human users. Unlike the fuels such as gas and oil, solar is a renewable energy source but as such it is an energy source which is not as readily controlled by turning it on or off at the whim of the user. As the solar building industry has developed in recent years, designs for active, passive and hybrid systems have become increasingly sophisticated and people are more aware of the utility of automatic control systems in optimizing the use of solar energy.

The market for solar buildings has changed in recent years. Solar features are now common in the conventional home market. The experiences of builders show that new home buyers are interested in saving money on heating bills and living in a comfortable internal environment. However, they do not want to be burdened with daily tasks to make the house "work."

The technology has become more sophisticated, but "keeping it simple" for the user has become increasingly important as solar features such as the ever popular sunspace permeate the production home market. As the market for solar in new and retrofit residential and commercial buildings expands, the technical and ergonomic issues of how the home energy system is controlled become more and more critical.

Past work on solar controllers and control systems, concerned primarily with active solar [1,2], has indicated a need for new microprocessor controllers in the future. Microprocessor technology has been used extensively for computer simulations and design analysis in solar, but very little has been done to apply the same computer technology to controlling the system once it is built and operating. Now, as the market for home energy controllers begins to expand, it is an appropriate time to reassess the use of controls not only in active solar design but also in passive and hybrid systems.

2.0 OBJECTIVES AND METHODOLOGY

The objective of the project was to:

1) investigate the present and future needs for controllers in the solar building industry,
2) outline the desirable specifications and features of such controllers,
3) summarize the features of controllers now available in the Canadian and U.S. market, and
4) recommend appropriate development efforts for new controllers.

In researching these areas the study undertook to provide the necessary background and a framework for analysis of control components of future solar projects.

The project methodology consisted of a technical literature search, product literature search, and a survey of solar designers. The review of technical literature focused on work done since 1980 when the last reports on controllers were published [1,2]. A product literature search was done to assess the availability of controllers suitable for solar building control functions.

3.0 RESEARCH ON CONTROLLING SOLAR ENERGY COLLECTION SYSTEMS

A controller is a device for regulating a mechanism or condition. The term controller as used in this report refers to a device used to regulate energy, specifically solar energy. The inputs to a controller are therefore the sensing of various conditions, primarily temperature and light in the case of solar energy. The outputs are the signals from the controller to direct operation of actuators such as fans, vents, back-up heating devices, and pumps.

The control strategy is the overall concept of what is controlled and when. For example, a temperature control strategy focuses on measurement of the temperature of the air in a room and maintenance of the desired temperature, whereas a comfort control strategy takes additional factors into account which affect human comfort. An algorithm is the procedure, the sequence of actions or recipe used to implement a given control strategy.

This report does not attempt to evaluate control strategies in general, but rather it focuses on the controller technology and the extent to which it facilitates implementation of control strategies. A summary of basic strategies for control of temperature in buildings is presented to provide background for subsequent discussion of the present uses of controllers for passive and active systems. The future needs for controllers in these areas and the technical specifications and features recommended for future controllers are discussed later in detail.

Interest in new controllers to regulate temperature in buildings has in part resulted from the advances in silicon technology in the past few years. The introduction of the microcontroller chip with a number of input and output ports has made it possible to implement sensing, control, and control logic with a minimum of components.

As solar building design has become increasingly sophisticated, the advances in microprocessor technology have made it possible to provide sophisticated control which can optimize energy use in specific control strategies. Research which pertains to the development of new controllers includes computer simulation studies of temperature control in solar buildings and work on control strategies.

3.1 GENERAL STRATEGIES FOR TEMPERATURE CONTROL IN SOLAR BUILDINGS

There are three basic approaches to controlling temperature in buildings. The first starts with the designer and features such as insulation, overhangs, natural air flow, and earth temperature moderation which are designed into the building form. The second approach is the use of manually operated design features such as opening and closing windows and manually regulated internal heat gains. The third approach is the use of automatically controlled devices such as thermostats and fans. Automatic controls may be adjusted by the occupant in many cases, e.g. set thermostats, but

will continue to operate without further adjustments. The most sophisticated form of automatic controls is the "smart" controller which can be programmed to monitor energy and comfort levels and make adjustments automatically. These three approaches are used, frequently in combination, to implement general strategies for control of building temperature.

Two of the basic goals of modern building design are energy efficiency and occupant comfort. There is general agreement that temperature control is integral to implementation of these goals, but there are many control strategies that can be used. Some strategies are straightforward and directly applicable, others are used in analytical methods leading to a control truth table or mathematical optimization. These analytical methods require further reduction into algorithms which are directly applicable.

TEMPERATURE

Temperature strategies involve the measurement of room air temperature and the maintenance of a desired temperature through passive and mechanical means. For example, to prevent summer overheating of a room and adjoining rooms, use fixed overhang, shades, movable shades, and ventilating. Controls can be used to keep a minimum temperature in the room with a thermostatically controlled heater or fan [3]. Air circulation and auxiliary heat are integral to temperature strategies.

COMFORT

Thermal comfort measurement is more subjective than temperature measurement. A feeling of comfort is a function of the temperature (mean radiant temperature-mrt or effective), humidity, air velocity, and clothes being worn. Other factors affecting occupant comfort in a building include visual comfort, air quality and acoustics.

Studies on thermal comfort indicate that people are not particularly sensitive to asymmetric radiation (thermal radiation from one surface, e.g. one window) [4]. However, a cool window does affect the mean radiant temperature and thus the operative temperature. Other research using TRNSYS computer simulations suggests the importance of taking infra-red radiation into account in comfort analysis [5].

Comfort zone charts have been developed [6]. To arrive at a more meaningful comfort temperature an equivalent uniform temperature can be used, Teu (Teu = 0.45Tmr + 0.55Ta), where Tmr is the measured mean radiant temperature and Ta is the measured air temperature [7]. Comfort conditions are compromised during the first few hours immediately following a period of thermostat setback or setup [8]. Results from passive building simulation using BLAST have shown that "comfort conditions in the standard building and the higher mass building do not appear to be substantially different if the same thermostat control strategy is used in both buildings"[8]. This last study is particularly

interesting in that considerations for thermal storage may not have to be considered when implementing a control strategy.

Visual comfort is associated with intensity of light, contrast, interior shadowing, and the transitions between daylighting and artificial light.

Comfort problems, particularly thermal and visual comfort, can have both direct and indirect impacts on energy use. Simulation research using BLAST suggests that properly accounting for thermal comfort will significantly alter the operation and the energy performance of a building [9].

TEMPERATURE ANTICIPATION

Short-term anticipation was added to mechanical thermostats in the 1950's to help prevent temperature overshoot and control cycling rates by adding a tiny heater (electric coil) to the thermostat to help anticipate the room temperature. Anticipation is less important in microprocessor thermostats since temperature overshoot and cycling rates can be controlled by the microprocessor.

Long-term anticipation does apply to buildings with large time constants (well insulated and sometimes higher thermal capacitance) or RC. RC is the product of the thermal resistance and thermal capacitance in the building. Most of the optimization routines require some form of weather anticipation to be effective. "For a typical building a look-ahead period of about 3 hours appears to suffice" [10]. In a study of optimal control for a passive solar building with an electrically heated thermal energy storage floor, results indicated that "some form of weather prediction is required if precise enclosure temperature control is to be maintained" [11]. Frequency response methodology (spectral analysis) has also been proposed to implement advanced algorithms. One approach [12] requires estimation of weather data over a 24-hour period, a spectral analysis of the data, and the system response calculated. This method requires a known transfer function to be previously defined but could be implemented by lookup tables or parameter estimation.

ADAPTIVE

Adaptive control is useful "where energy tradeoffs must be made and the control strategy for the tradeoff is not intuitively obvious" and/or "the control strategy changes with changing conditions" [13]. In one study an adaptive algorithm in conjunction with a two-speed collection mode (as a result of a computer-based study) was used to approximate a variable-speed controller. It was found that an adaptive anticipator based on outdoor temperature was effective in minimizing temperature lag and overshoot and in increasing comfort [14].

PROPORTIONAL

The study of the difference in performance between "bang-bang" (on-off) and proportional control methods (i.e. the amount of solar energy delivered is proportional to the solar energy available) has been a popular research topic for active solar energy systems [15, 2, 16, 17, 18, 19]. Results vary but the general consensus seems to favour on-off controllers for locations with generally clear weather and proportional for cloudy locations. On-off controllers tend to cycle more often.

PROPORTIONAL PLUS INTEGRAL

Proportional control varies heating/cooling in proportion to the error between the setpoint (desired temperature) and the actual temperature. Proportional action alone makes a relatively coarse correction to the position of the actuator. The addition of the integral control component (proportional plus integral) allows for a greater degree of accuracy. The integral action moves the actuator towards the desired setting with decreasing speed until the remaining error is gone. This control strategy is becoming more common on commercial thermostats [20] and may have direct application if a variable-speed (or multi-speed fan is used between one zone and another zone). An optimal control algorithm was compared to conventional controls leading to a five to ten percent improvement for a solar augmented heat pump system [21].

OPTIMAL

A study compared three different kinds of control strategies for optimal control of active solar systems [22]. The author points to the need for development of a variable-output furnace for implementation of two of the three schemes. Electric resistance heaters can be used.

THERMAL STORAGE

Rules have been developed for charging the backup storage device for active solar systems: 1. on demand, 2. fully recharge during every off peak period, 3. storage device recharged during the off-peak period to a level sufficient to satisfy demand during subsequent on-peak period based on expected temperatures during that period, 4. storage device recharged during off-peak period to a level sufficient to satisfy demand during subsequent on-peak period based on expected temperatures and solar collection during that period." Items 3 and 4 require weather prediction. The author suggests that the local electric utility could send out a signal using radio or ripple control to control the backup storage charging [23].

PEAK-LOAD REDUCTION

In areas where peak solar radiation occurs in the same time frame as peak hot water demand, peak-load reduction can be implemented

by disconnecting the bottom element in an electric hot water auxiliary heater when solar energy is available [24] or at certain times of the day. Three analytical means of optimally controlling peak-load reduction are presented including a "self-tuning regulator" which minimizes the difference between the desired temperature and the building enclosure temperature based on real-time measurements. The method requires known building parameters (by using a Kalman filter) and computation of the optimal amount of heat to supply [25]. Peak-load reduction schemes may become more important in Canada if more utilities begin using peak-loading rate structures.

ZONE

If the building is divided into separate heating/cooling zones it may be appropriate to decrease the temperature of certain zones based on an occupancy schedule. Each room could be controlled separately (cellars and storerooms can be at lower temperature) [26].

INTERNAL GAINS

In well insulated buildings, internal gain (heat from appliances, people, etc.) may be important as part of the control strategy [27].

3.2 SOLAR BUILDING SYSTEMS

For passive solar design the term "controls" has conventionally referred to manual or built-in mechanisms or design features which aid in the circulation of air and maintenance of temperature. Thus vents, fans, heaters, shades, fixed overhangs and even doors are frequently referred to as controls which regulate the transfer of heat and keep temperatures within desirable ranges. Fans and heaters may be automatically controlled using sensors and thermostats while doors and shades are usually manual controls.

Research on building performance has demonstrated that both residential and non-residential buildings are good candidates for passive solar technology [28, 29, 30]. Passive solar design can provide for space heating, cooling, and daylighting which can save energy at little or no extra cost. The main control problems are the distribution and storage of solar gain and the regulation of daylighting. Both temperature and light control contribute significantly to the satisfaction and comfort level of the occupants.

CLIMATE-DEPENDENT DESIGN

Temperature control in passive solar buildings is partly contingent on climate-dependent design. The thermal environment of both active and passive systems is very important as well as the solar radiation environment [31].

Consumers in all climates have been attracted to large window areas and sunspace environments [32]. However, improper sizing of solar apertures and inadequate shading have led to many problems with overheating [33].

THERMAL ZONES

Most passive solar homes have distinct thermal zones. Monitoring has shown that the houses with separate thermostats for several different zones have more even temperatures from room to room [29]. Given that a design suits a particular environment, good internal air circulation leads to more even internal temperatures.

To achieve good internal air circulation a variety of mechanisms is used. Design of the internal building space is critical for air circulation in passive solar buildings. Air circulation can be assisted by passive means such as automatic backdraft dampers which use bimetallic coils to activate them [34]. Non-automatic passive means include manual operation of windows, doors, and vents. Mechanical devices are commonly used in conjunction with passive solar design. For example, a simple way to circulate air is a fan activated by a temperature sensor.

MECHANICAL SYSTEMS

Various types of mechanical systems can be used with passive solar design to improve energy savings and comfort. In one study four types of mechanically enhanced passive solar thermal storage were built and later simulated with ENERPASS [32]. Study of the four systems--forced-air-coupled building mass, reversible air flow rockbed storage, domestic hot water heat pump, and integrated systems with isolated storage--showed that through the use of mechanical devices there is significant potential for increasing passive solar contribution while maintaining good comfort control.

DAYLIGHTING

Daylighting control is largely a problem of reducing glare, using available daylight, and minimizing lighting discontinuities as the transition is made between artificial lighting and daylighting. Some researchers conclude that automatic controllers are necessary to obtain energy savings from the use of daylighting. The challenge is to integrate daylighting with electrical lighting system controls [35, 36]. There are basically three control strategies: switching, dimming, and switching plus dimming. The controls which are presently used range from manual operation of switches and shades to automatic dimming devices and automatic shades.

The problem of bringing daylight into areas deep within a building has led to a variety of passive methods for concentrating and directing sunlight. Distribution of sunlight through light pipes has been studied both using a tracking

parabolic reflector with optical feedback and using a plane mirror heliostat with polar axis mount in conjunction with a fresnel lens concentrator [37]. Supplemental illumination was provided with metal halide lamps powered by a dimming electronic ballast controlled with optical feedback.

One hazard of improper daylighting design is that large areas of horizontal roof apertures, e.g. skylights, can result in user discomfort. Use of ceiling fans, use of variable-transmission glazings, and changing the cooling thermostat set point are three ways of dealing with this problem while still allowing for daylighting [9].

CONTROL ISSUES FOR SOLAR BUILDINGS

Several basic control issues emerge from the research on passive solar design. Monitoring of occupied passive solar buildings has shown that the use patterns of the occupants are critical in the overall performance of many buildings [28]. For example, movable window insulation was used properly only seventy percent of the time in one study [28].

One recurring conclusion in the literature is that the solar and the conventional heating, cooling and lighting systems should not be treated as separate systems. The building design and the mechanical system should be an integrated design [28, 29].

A second conclusion from the literature is that both architectural and mechanical design of passive solar buildings should be kept simple [29]. This is important in three main respects: one, facilitating integration of solar and mechanical systems; two, ease of installation and maintenance; and three, ease of occupant use.

One of the important issues about which there is little consensus is the degree of user control. Monitoring of non-residential buildings has shown that in some circumstances manual controls are more energy conserving than automated controls. Users may use lower levels of heat or lighting than is specified if they have manual control [28]. What is difficult to estimate is the extent to which users are committed to energy saving.

The importance of simplifying what the occupant has control over has been demonstrated in studies which indicate that energy bills in identical houses can vary by a factor of two depending on the use patterns of the occupants [38]. Controls are only one component in the use patterns but it is a significant issue for both passive and active design.

3.3 ACTIVE SOLAR ENERGY SYSTEMS

Automatic controls are most extensively used in active solar design. For many years the majority of available controllers have been differential thermostats designed for regulating domestic water heating (DHW) or for the collection cycle of solar

space heating systems. In many of the newer solar buildings these types of active systems are combined with passive solar and other systems such as heat pumps. The increase in these "hybrid" systems has led to the need for automatic controllers capable of integrating the energy system to achieve greater efficiency and ease of operation.

Previous studies of solar controls have focused on active solar designs. An NRC study of solar system control strategies and control systems produced in 1980 used data from case studies of solar space heating and domestic hot water systems [2]. Although this study concentrated on solar system design and control strategies, several conclusions were reached about the use and design of controllers for active solar systems. The study stresses that the electronics for a solar control system should be considered from a systems viewpoint and suggests that "the ultimate (!) solar system will undoubtedly be used in conjunction with a home (or office/factory) energy controller"[2].

In a study of the needs for new controllers prepared for U.S. DOE in 1980, a survey was made of representatives, from manufacturers to designers, of the solar industry [1]. The author concluded that many of the control problems are associated with interfacing solar and conventional systems and that because of this, more elaborate control strategies and microprocessors to implement them are becoming necessary.

In the six years since these two studies were made, active solar design has incorporated increasingly sophisticated controls.

DOMESTIC HOT WATER SYSTEMS

In the past six years there has been increased interest in "low flow" domestic hot water systems. Research has demonstrated that thermal performance improves with reduced flow rates [39, 40]. Low flow systems save energy, simplify design, and simplify installation: collector and piping costs are reduced, lower pump power is required, and controls are simplified [41].

There has been some interest in passive systems for domestic hot water which require no controls, for example the bubble action pump system [42]. Although passive systems are widespread throughout the world, most systems in N. America are active and interest in passive is recent. The concern with freeze protection in N. America and N. Europe has stimulated interest in freon systems which may be an important trend in the future.

HYBRID SYSTEMS

Just as active mechanisms are now being used effectively to enhance passive solar systems, passive features are being incorporated successfully in active solar designs. Various systems have been designed which use an active charge and a passive discharge [43, 44]. The passive release system may use no controls while the active part uses collectors, heat

exchanger, pump and generally a differential controller. An evaluation of a hybrid system using active charge/passive release with a radiant panel slab concluded that the net amount of solar gain is significantly higher than would be expected from a purely active or passive system and good comfort levels were maintained [44].

Analysis of a system using a water source heat pump in a sunspace showed that the combined net energy yield of the sunspace increased by eighty-four percent with little effect on the ratio of heat supplied to electrical energy of the heat pump with space heating. The ratio was increased by using a timeclock to force it to operate in a batch mode [45].

3.4 COMPUTER SIMULATIONS

This section does not attempt to summarize all simulation research, but rather summarizes some of the work which is of interest with respect to controllers and future directions in solar design.

Computer simulations have been used extensively in solar research for both defining design parameters [49] and evaluating performance of buildings. For example, computer simulation has been used to determine the thermal performance of different design alternatives for solar buildings. One study examined the use of passive and active measures to reduce discomfort from heat and concluded that a combination of passive and active measures is most effective in passive design [50]. The computer program (Solar C) was developed specifically to simulate solar systems and their control systems [15].

Another system, developed to monitor and analyze collected data on test systems and to design and implement control strategies, is the microcomputer based data acquisition and control system (DACS) developed at the University of Waterloo [51]. This system has been used to study DHW and scale solar industrial process heat systems. It uses an IBM PC linked to a Hewlett-Packard HP 3421A Data Acquisition and Control Unit and has the potential for powerful analysis.

The simulation program TRNSYS has been used for many types of solar analysis. In one study a microprocessor simulator was added to TRNSYS. It uses comparison of inputs and a truth table to produce the appropriate output control signals. A truth table is a table of input states and output states. An input state is a distinctive combination of input comparisons. All possible input states are included. For each input state a corresponding output is chosen. For example, if the temperature is higher in an attached sunspace than in the parent building (input state), then turn on the fan in the common wall to move heat from the sunspace to the house, (output state). The author concluded that a truth table approach to control implementation was the best approach for the TRNSYS microprocessor controller simulation since the entire energy system must be considered in

an analysis and control functions are analytically complicated [52].

Another study using TRNSYS examined the effects of temperature control strategies on three types of sunspaces: 1. heat producer, 2. living space, 3. plant producer. Use of movable insulation improved performance of all three types. Use of thermal storage only improved the performance of the plant producer. Performance of types 2 and 3 decreased when the minimum air temperature was increased in the sunspace. Use of forced ventilation increased performance over natural ventilation systems [53].

A computer program, DOE 2.1, was developed to study detailed thermal interactions in buildings. DOE 2.1 has been used as a benchmark in building design because of completeness and the ability to simulate controller operation. A sunspace modeled on DOE 2.1C at LBL was studied [54]. The sunspace was simulated to be occupied during the day and not allowed to freeze at night. The study concluded that a sunspace generally had the most value when connected to a house with high air infiltration rates [54].

Simulation is a powerful tool in the analysis of physical system performance and can effectively evaluate fault diagnosis algorithms run against monitored data for this purpose [55]. Physical buildings are difficult to monitor and it is difficult to study the effectiveness of controls due to variation in occupant behaviour and other anomalies. Advanced controllers will need to be developed to perform in different climates with different buildings with different occupants. As the algorithms are refined, the controllers will use the local climate and building information to a greater degree then previous generation controllers. It will be advantageous to use computer simulation tools to "fly" various building designs, changing the weather, control set-point parameters, refining the algorithms, and to fault test the controller.

3.5 ADVANCED CONTROLLERS DEVELOPED

Since solar building design and microprocessors have been developing during the last decade, the technology in many cases is growing together. Hence, much of the research on advanced controls has been done with solar buildings.

Advanced controllers have been developed for the control of building temperature systems [56], hot water heaters [57], and to control a four speed fan using a twenty-five entry look-up table at a solar research house [11]. A 6502 processor was used [26] to implement a discrete control algorithm with a macro-based pseudo-high-level language including BCD floating point arithmetic. A home energy system was designed around a PET home computer [58]. In another study a digital controller was developed by implementing a control truth table in a PROM [59]. A programmable controller was developed with display (up to eight temperatures) and status indication (controlling up to 16

devices). The controller required reprogramming for each new application [60]. A programmable logic array (PLA) was used to implement control logic. The controller was designed to require no intervention from the owners and included a flow chart indicating "all possible conditions." LEDs were used for status indication. A separate LED indicated need for servicing [61].

A microprocessor controller was developed for optimal building control [62]. System parameters were entered via a Hex-decimal keyboard. Once the values were entered a loop was implemented which included: time sampling, sampling data, adjusting design temperature for specific times, computing optimal control strategy, and controlling the output to analog devices. In addition, the controller could calculate the effective UA.

A solar energy management system was developed using a microprocessor. The system consisted of three parts: a wall mounted control panel, a remote solar electronics module, and a system initialization panel. The wall mounted panel provided a display and user programming. The controller had a portable plug in device for programming the controller [63].

The advanced controllers described in this section were all prototypes. Although these prototypes did not make their way to the marketplace their use furthered the research of computerized building control.

3.6 GENERAL TRENDS IN CONTROLLER APPLICATIONS AND REQUIREMENTS

Within the next ten years buildings that now contain a variety of fractional horsepower motors will undoubtedly contain as many if not more microprocessor devices. Occupants of buildings will get more accustomed to "programming" devices. A computerized thermostat will be little different than living with a microwave with programmable features. Future controllers will not only include advanced algorithms but also will be smaller and use less expensive components.

There are two trends at present in the use of controls for solar building designs. One is toward keeping designs simple enough that the controls components are also simple and often manual. The second trend is toward increasingly sophisticated designs which incorporate passive and active solar (together or separately) with other energy efficient technology.

There are a number of other important trends in solar design. One trend which effects both active and passive solar design is the higher level of energy conservation in building construction. Methodologies have been developed for calculating the optimal split between economic investments in passive solar versus conservation in houses to minimize total heating and cooling costs [46]. A mix of strategies is recommended to minimize the life cycle cost of the building. Contemporary solar design is frequently combined with low energy design resulting in a need for air-to-air heat exchangers. Smaller solar energy systems can

be used in many instances when combined with "super window" technology and low energy design [47].

A second tendency is toward the use of natural lighting. In commercial buildings about one third of the total energy use is often for lighting. Daylighting designs can result in substantial energy savings if they are carefully integrated and they can substantially reduce peak demands. Partly because of the use of daylighting, atriums have become an increasingly popular design feature for commercial buildings and the new window glazing products make this type of design increasingly practical.

The combination of conservation and daylighting tends to favour solar systems that combine both active and passive features. Hybrid solar systems are proliferating in many forms: active collection and storage systems with passive discharge, passive gain with active distribution, and heat-pump-assisted systems are three of the main types. Work with large-scale integrated systems, for example in rural communities, suggests the need for systems which are integrated, reliable, and flexible for change [48]. To enable these systems to work as an integrated whole, control systems which assure continuity of energy supply are essential. The necessity for well-integrated designs increases the need for sophisticated controllers to control such systems and buildings.

Many of the problems of both active and passive solar systems in the past have stemmed from the fact that designers did not fully consider the willingness or capability of building occupants to cooperate. Active systems are frequently too complicated and are not understood by occupants well enough to be properly operated and maintained. Passive systems often require occupants to make adjustments such as operating night window insulation [47]. The future direction of solar design appears to be one of greater sensitivity to these human interface aspects through reducing occupant participation in the operation of the system.

A related trend is towards the packaging of components, particularly for active systems such as domestic hot water. Packaged components have been shown to be more successful because of fewer problems with installation and maintenance [39].

Previous research indicates that although presently used control systems may be adequate in some situations the use of microprocessor controllers will enhance the capabilities of solar design to provide energy efficient and comfortable buildings.

Use of a microcontroller system for control implementation provides additional benefits over using discrete components. A digital display can easily be added to indicate the time and temperature at different locations. A real time clock can provide the time of day, allow 7 day programming, and provide the control of appliances on a time schedule, e.g. the hot water heater. By adding memory, data such as high and low set points,

the minimum/maximum temperature, or a weeks' worth of temperatures can be stored. The math capabilities of a microcontroller allow for the use of inexpensive non-linear sensing devices, e.g. thermistors. Advanced algorithms for the control of buildings can be implemented as they are developed since the microcontroller circuit is programmable and can do mathematical manipulation.

DATA ACQUISITION

There are benefits to collecting performance data on buildings, i.e. utility load schedule analysis, building operation diagnosis. Some requirements for detailed study of buildings require measurement of conduction heat transfer (through solids), heat inventory of nonisothermal masses, comfort conditions requiring heat flux sensors on walls, temperature transducers in thermal storage components, mean radiant temperature measurement, solar radiation (solar cell solarimeter or pyranometer), humidity of internal spaces and ambient, atmospheric pressure (to calculate air flow rates) [65]. Low level monitoring could be accomplished with an enhanced controller with its sensors and data collecting abilities and additional sensors on the utility meter and/or furnace.

Level 2A and 2B (SERI) monitoring results indicated usefulness of telephone communication ability for 1. instantaneous reading of current events, 2. access to past histories, 3. indications of problems [64].

DEVELOPMENT OF NEW ALGORITHMS

There is a need for the study of building temperature control algorithms as they pertain to buildings. There are some existing tools available for study. An analog computer was developed which could be used to test control strategies (Solar-C) [15]. A synthetic weather (stochastic) model was used with the SHASP computer program to study the effect of control strategies during a cooling season with good results [14]. Two programs (SUNSIM/DYNSIM) were used by Honeywell to evaluate control strategies, e.g. automatic thermostat night setback, and storage management for peak load avoidance [66]. The study noted that the cost of the control actuators was a significant cost of a control system.

A method was developed for the study of temperature swings in direct gain rooms which uses network theorems and frequency domain techniques and presents an algorithm for estimating the frequency of occurrence of swings above a critical value [67].

CONTROLLER DESIGN ELEMENTS

Various requirements for new controller design have been suggested in the past [68,2,70]. There is general consensus that the least expensive controller is the most likely to be chosen. Cost-effectiveness is clearly an important factor. It is

also generally agreed that new controllers should be more reliable.

Specific design elements suggested have included modular design, digital controls, interchangeable temperature probes, large-scale integration chips, and software capable of integrating the whole system controlled. A need for improved sensors and actuators has also been noted. With regard to installation and maintenance the modular design has been suggested as one means to reduce servicing, along with clear labeling and test points.

Maintainability is essential for control systems. Experience shows that if the controllers are not easily maintained control systems will not function at their best. Various procedures are recommended for maintainability [69]:

1. easy access, well labeled,
2. use of 'generic' components, no unusual applications,
3. maintenance documentation including labeled control schematic, labeled electrical ladder diagram, description of the control strategy, and functional description of each control component
4. maintainability review by operators of system.

One study stresses the need for consideration of human factors [70]. It points out the importance of matching the program to the level of user skill, minimizing human memory demands, and providing for error checking. If the use of programmable controllers is to be widespread these human factors may be equal in importance to the hardware considerations for future controllers.

3.7 THE BUILDING INDUSTRY AND SOLAR CONTROLS

A survey was conducted to obtain current information on what people in the solar building industry think are the present and future needs for controllers. A list of about eighty architects, engineers, researchers, installers, suppliers and manufacturers was compiled out of which forty telephone questionnaires were completed (see Appendix B for the survey form and list of participants). Some companies were no longer in business, others were no longer involved in solar, and some could not be reached for other reasons. The sample is representative in that it does include respondents from each field of the solar industry (Figure 3.1). The survey focuses on the Canadian solar industry and eighty percent of the respondents are Canadian with the remaining twenty percent consisting of solar researchers and designers from the United States.

Thirty-eight percent of the respondents work with active solar, twenty-eight percent work with passive, and the rest work with both passive and active, low energy design, or all types of buildings (Figure 3.2). Most responded that they deal primarily with space heat and domestic hot water systems (Figure 3.3). Pools and industrial process heat are the next most frequently

mentioned types of systems worked with. Forty percent of those responding work with single family, multi-family, and commercial systems, while twenty percent work only with single-family residences (Figure 3.4). Overall, the majority of the respondents work at least part of the time with passive solar and fifty-eight percent work at least part of the time with commercial buildings. Those working solely with active solar included most of the installers and manufacturers.

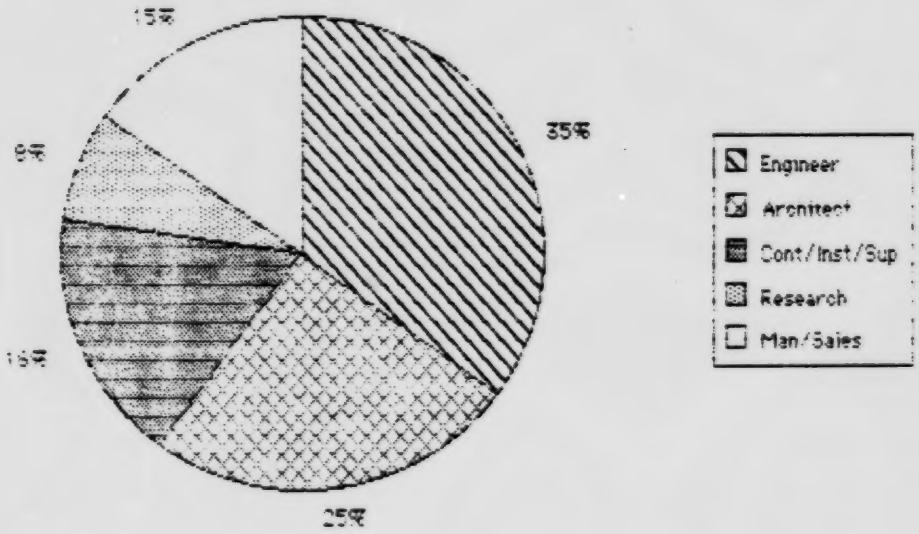

Figure 3.1 Occupation

Respondents were asked if presently manufactured controllers are adequate for their needs. Forty-four percent said no, forty-one percent said yes, and fifteen percent said they are adequate only for some purposes (Figure 3.5). The additional comments in response to this question indicate that the ones answering "yes" are mostly using simple thermostats or are manufacturers who build their own controllers. Comments suggest that controls for solar domestic hot water systems are generally adequate. Nevertheless, problems were noted with respect to using U.S. made controllers that are not CSA approved. Other comments said that controllers are the "weakest" aspect of solar building design, and that improved controllers are needed for passive designs, especially commercial, which could integrate building mechanical and lighting systems. Interface between controllers and equipment is a problem: according to one respondent "it would be nice to get a few things to work together well." Another concluded, "generally there is room for improvement", although clearly some of the respondents take the approach of "adapting what is available to fit."

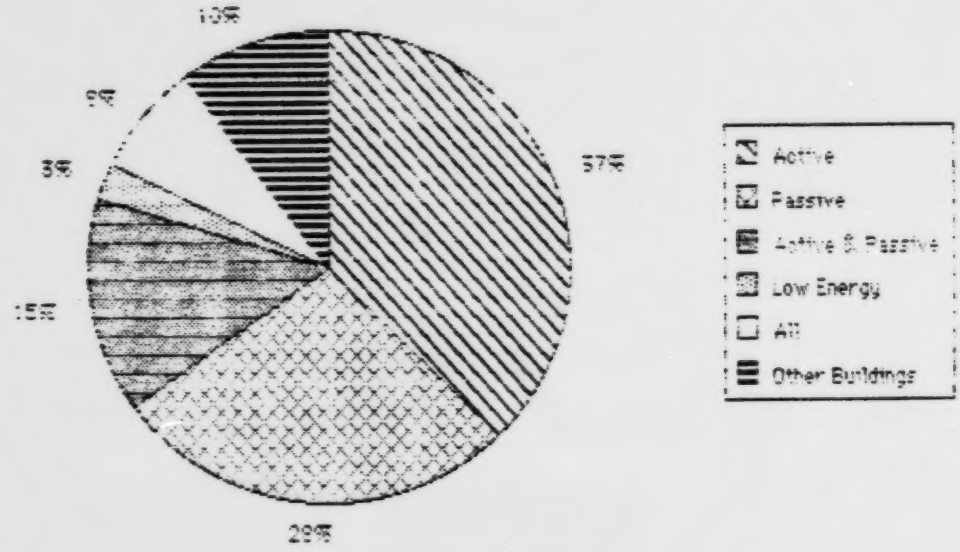

Figure 3.2 Type of Systems/Buildings

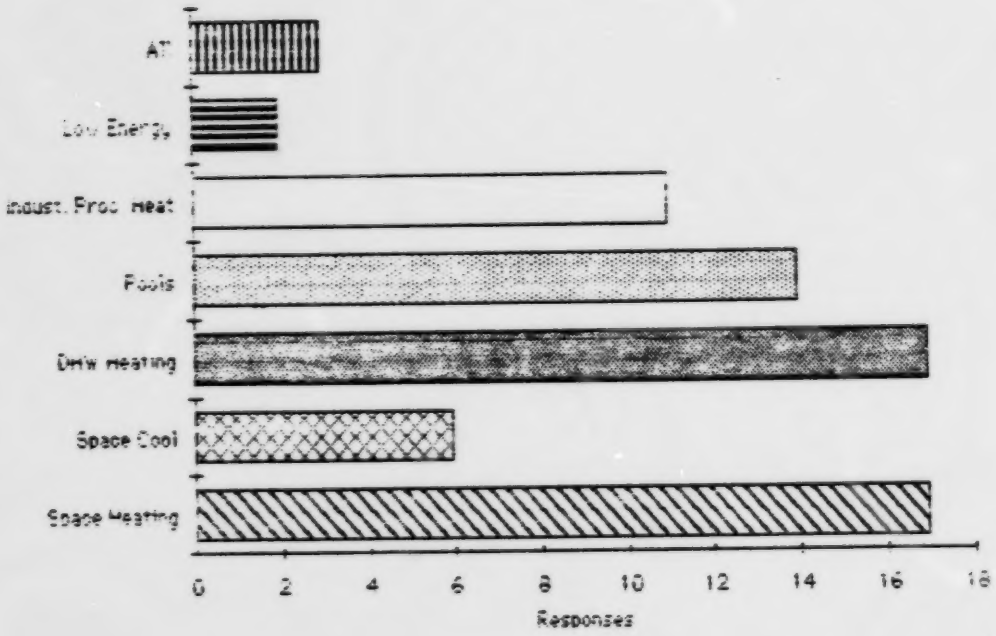

Figure 3.3 Type Systems/Buildings

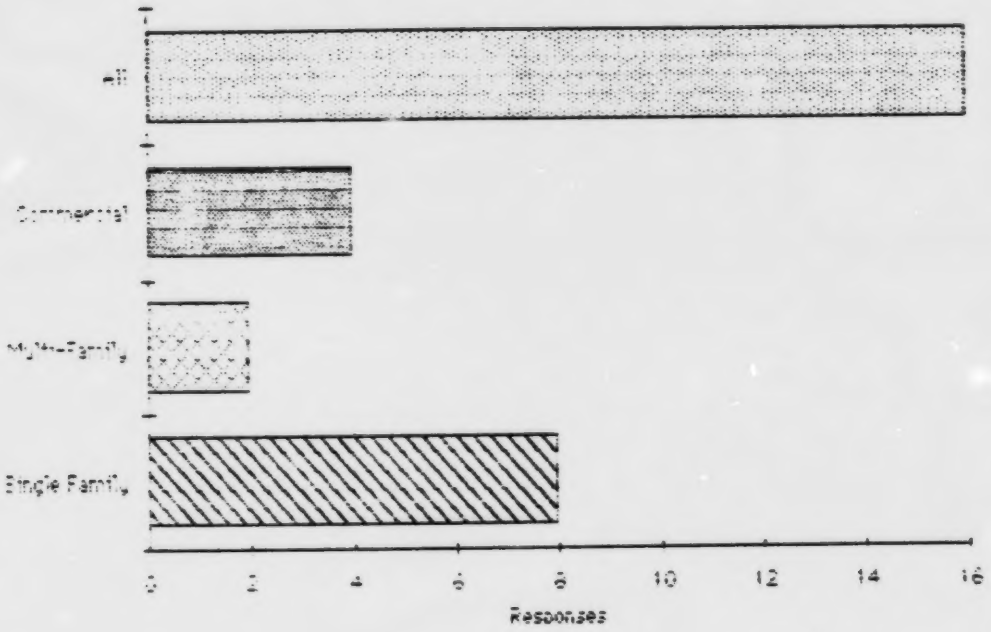

Figure 3.4 Building Types

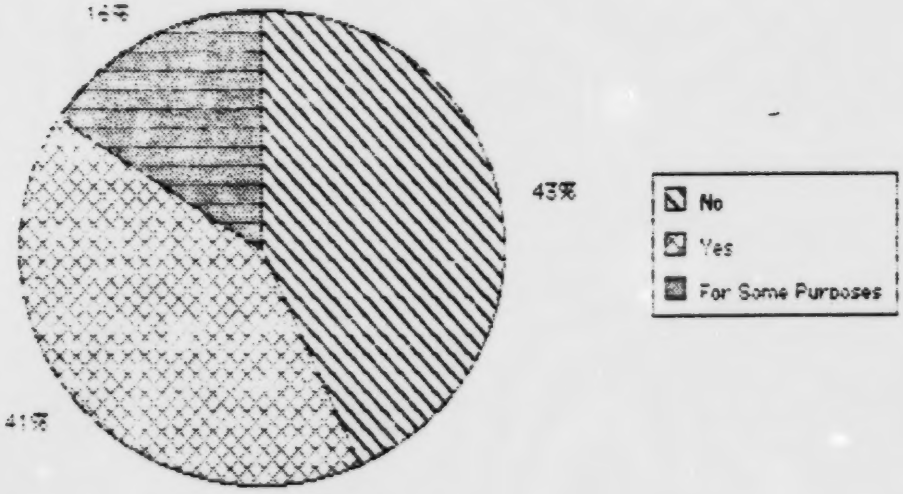

Figure 3.5 Controllers Adequate for Needs?

Respondents were asked what are the major shortcomings of existing controllers. The three shortcomings mentioned the most were limited control logic, unreliability, and difficult for user to operate (Figure 3.6). The comments evoked by this question focused on the problems of the user operating controllers and the trade-offs between simple and more sophisticated controls. Simple controllers may be easier for the user to operate, but there is also a need for more sophisticated and precise controllers. One respondent commented, "if you make controls general, then you lose some features and end up with the wrong features for a given application." However, "one problem with more sophisticated controllers is that they cost more." Some respondents noted specific areas in which new controllers were needed: heat pumps, low temperature radiant heat panels, daylighting, comfort control, and individual zone control in commercial buildings.

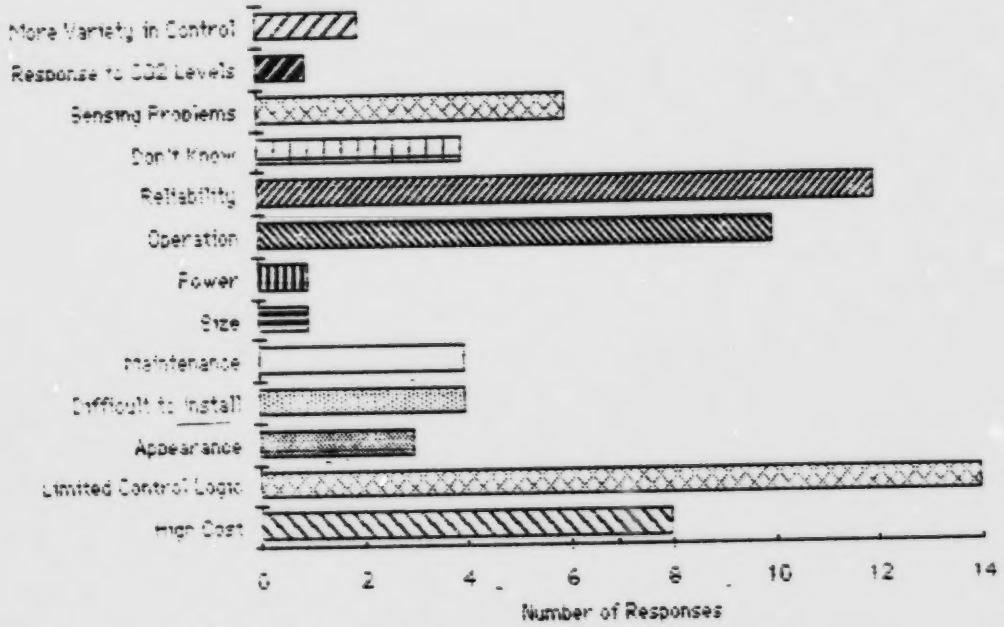

Figure 3.6 Shortcomings of Existing Controllers

Most respondents, seventy-six percent, stated that automatic controls are preferable to manual controls, the remainder stated that they were preferable some of the time (Figure 3.7). Comments on how you decide which is preferable suggested that people generally do not understand thermal lag in buildings and therefore should not be allowed to manipulate the controls, especially in commercial buildings, although zone control may be desirable. Only three respondents suggested trying to use systems that do not require controllers. It was generally stated that some manual controls or override are necessary, e.g. access to set points. Several respondents suggested that the problem with manual controls is that occupants and personnel change. Even if the first occupant understood the system the subsequent

users are unlikely to be properly trained in its operation. Advantages to keeping control systems simple were noted such as the use of simple automatic timers in the bathroom to operate vents. Basically the comments indicated that the decision of whether or not to use automatic controls is based on the user. In addition, manual controls are more frequently used in single family residences because of the lower cost.

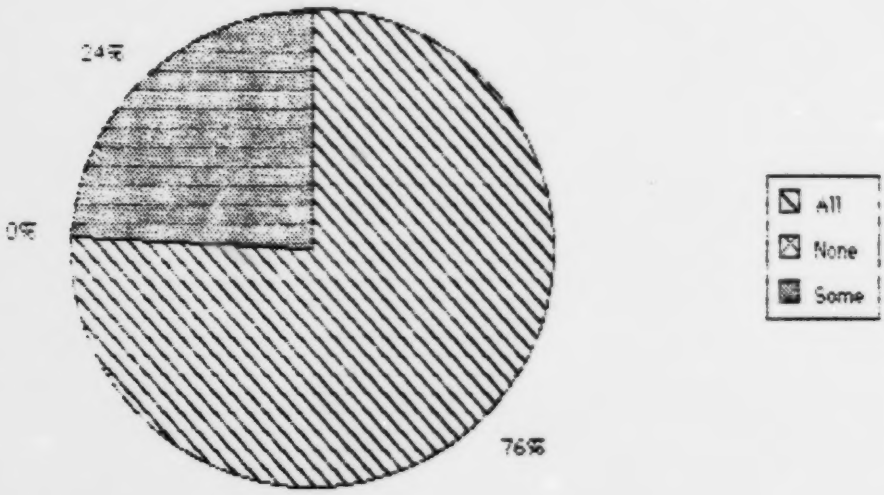

Figure 3.7 Situations Automatic Controls Preferable to Manual Controls

The features which were most frequently stated as important in selection of a controller were cost, ease of use, and the ability to perform a specified task (Figure 3.8). Ease of installation, maintenance, and overall reliability were also important. When asked which of these features was the most important the highest priority was assigned to reliability and ability to perform a specified task, followed by ease of use and cost.

The majority of the respondents, fifty-six percent, thought that the user should not be able to program a controller (Figure 3.9). Twenty-three percent stated that the user should only be able to change time and temperature, while others thought that the extent of user control depended on the type of user and the type of controller. Comments indicated that users are not well versed in temperature control, e.g. "one half of the population does not understand how a thermostat works" and "eighty percent of users do not understand thermodynamics." The problem is that if the user doesn't program the controller then who does? A few comments suggested that the installer be responsible for programming changes and making adjustments to suit subsequent occupants. Several respondents again noted the need for manual override.

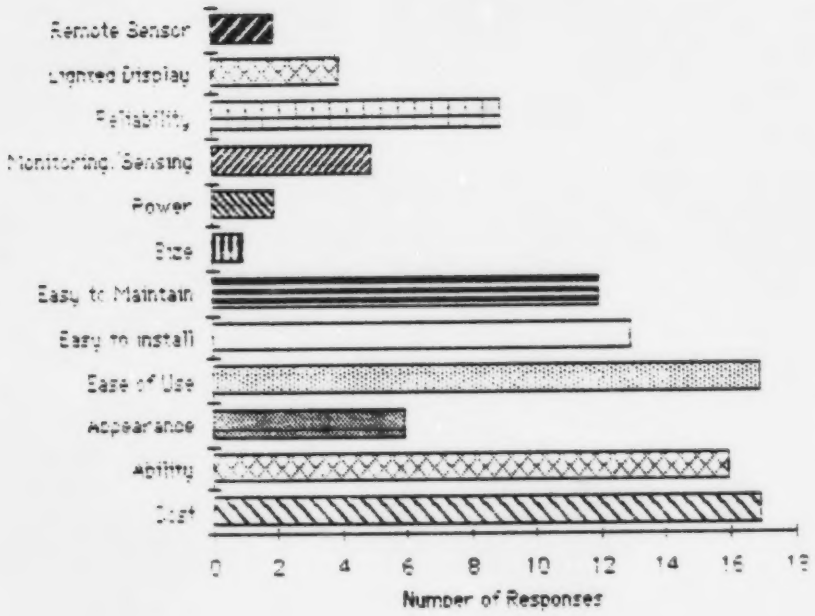

Figure 3.8 Features Most Important

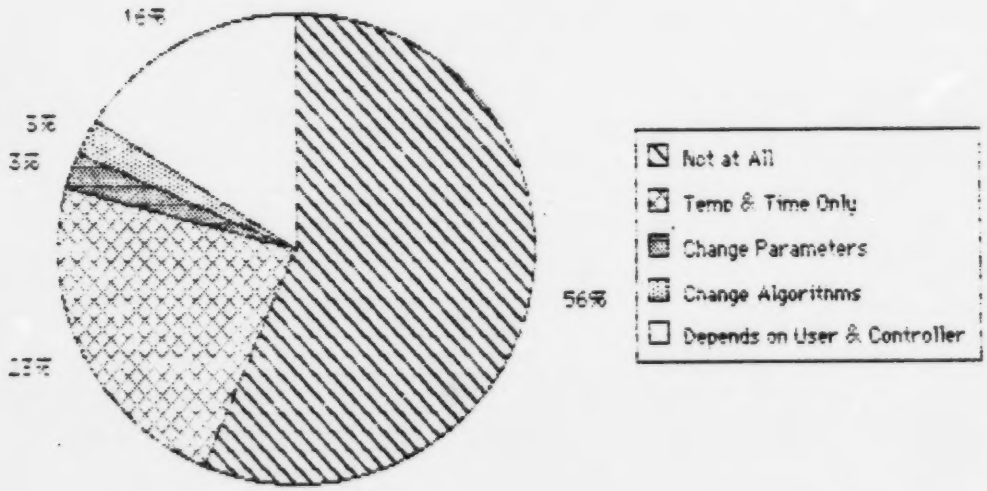

Figure 3.9 User Programming

Suppliers were a main source of information on building control for fifty-seven percent of the respondents. Thirty-two percent relied in part on trade magazines, twenty-seven percent use consultants, and ten percent used only in-house sources (Figure 3.10).

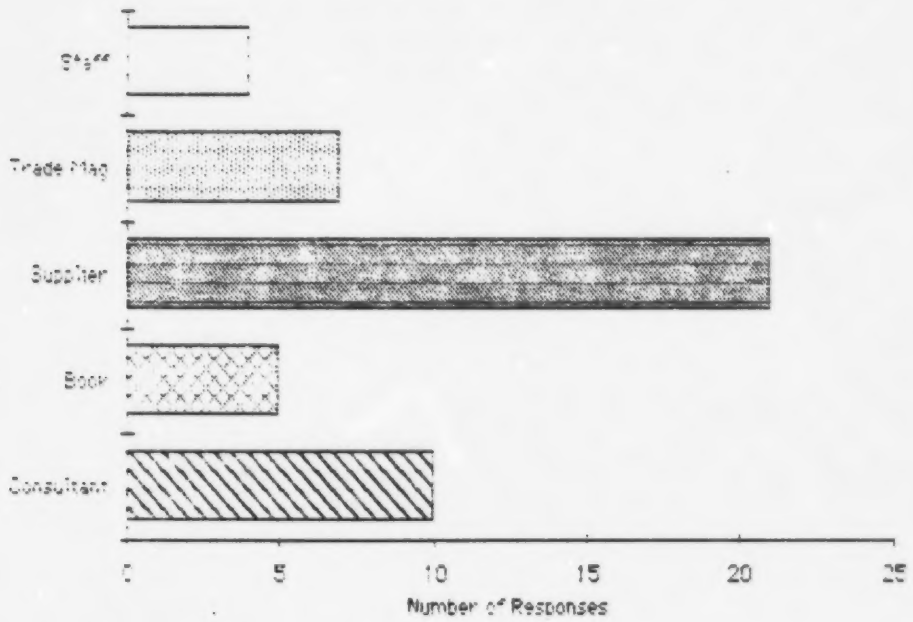

Figure 3.10 Information Source

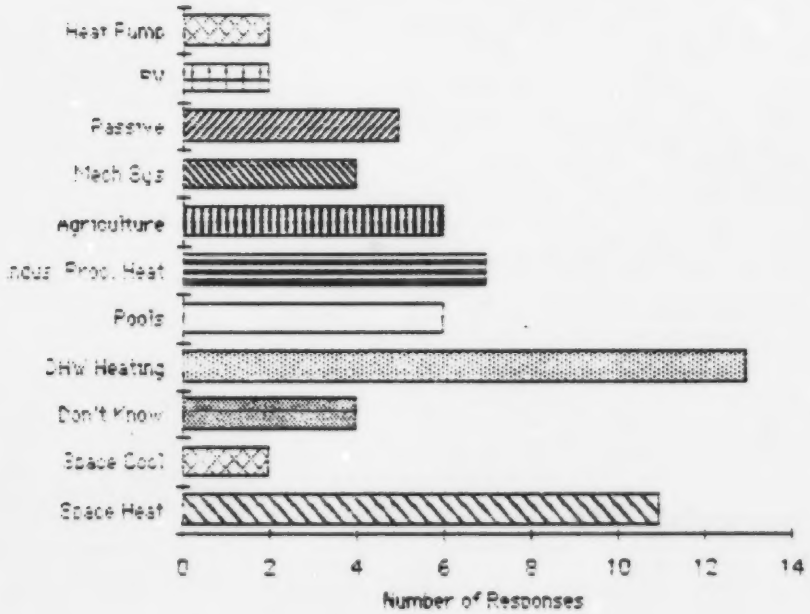

Figure 3.11 Growth

Two questions were asked pertaining to the future of solar. The first asked which type of systems they thought would show the greatest growth in the next five years. Domestic hot water systems had the greatest number of responses, followed by space heat, industrial process heat, pools, agriculture, and passive (Figure 3.11). In a similar but more open-ended question respondents were asked what they thought were the best new ideas or new directions in solar energy. The overriding emphasis was on passive solar. The majority of the forty-seven items mentioned are associated with passive solar. Responses included agricultural systems, heat pumps, batch heaters, low flow domestic how water, lower cost, furnace sizing, low energy designs, new materials, daylighting, and photovoltaics. The most frequently stated "new ideas or trends" were passive design, super windows, and integrated mechanical systems (Figure 3.12).

In summary, the majority of survey respondents from the solar building industry were not completely satisfied with existing controllers. Dissatisfaction centered on building controllers and integrated systems, while controls for domestic hot water and pools were generally thought to be adequate at present. Comments on future trends in the solar field emphasized integration of passive solar and low energy design and the need for integrated mechanical systems. It is in exactly these areas that the greatest shortcomings of existing controllers were cited by respondents, e.g. limited control logic for sophisticated systems, and user interface. Even for generally satisfactory controls, the problem of unreliability was an overall concern. The survey results showed that designers rely heavily on suppliers for their information about controllers and clearly some designers as well as users have a limited understanding of controllers.

A number of differences are apparent when these results are compared with those of a survey conducted in the U.S. six years ago [1]. Results from the present survey indicated that ease of use of a controller is important and that sophisticated control may be preferable partly because most occupants do not understand thermal control in buildings. This point was not discussed in the report on the U.S. survey, but it is notable that the number of programmable and potentially confusing-to-the-user controllers has increased since that time. Another significant difference is in the current emphasis on hybrid systems rather than the emphasis on active solar space heating and domestic hot water reflected in the work published six years ago. The "integrated control systems" and the microprocessor controllers which the previous survey indicated would be the way of the future are now available. The present survey indicated, however, that they are far from perfected.

Review of the literature and a survey of representatives in the solar building industry indicates that there is a perceived need for different controllers in some design situations. There are five basic reasons why there is dissatisfaction with presently used controllers:

1) it is complicated to use discrete components to provide for integrated control strategies,
2) flexibility is needed in order to accommodate changing circumstances and occupant needs,
3) problems frequently occur with installation and maintenance of more sophisticated systems,
4) components such as sensors are unreliable, and
5) the cost/performance ratio should be improved before advanced controllers will be more attractive to the residential market.

4.0 TECHNICAL & ECONOMIC ISSUES FOR SOLAR CONTROLS IN THE CANADIAN CONTEXT

4.1 INTRODUCTION

Designers recognize that controls are a necessary and important part of solar design. In this section the observations from the literature review, designers survey, and sampling of products are integrated with discussion on controls as a system, the components, and some specific issues relating to controls and solar buildings in the Canadian climates.

A SYSTEMS VIEWPOINT

Automatic control of comfort and energy use in a building or solar energy system has three main system components: sensor, controller, and actuator (diagrammed in Figure 4.1).

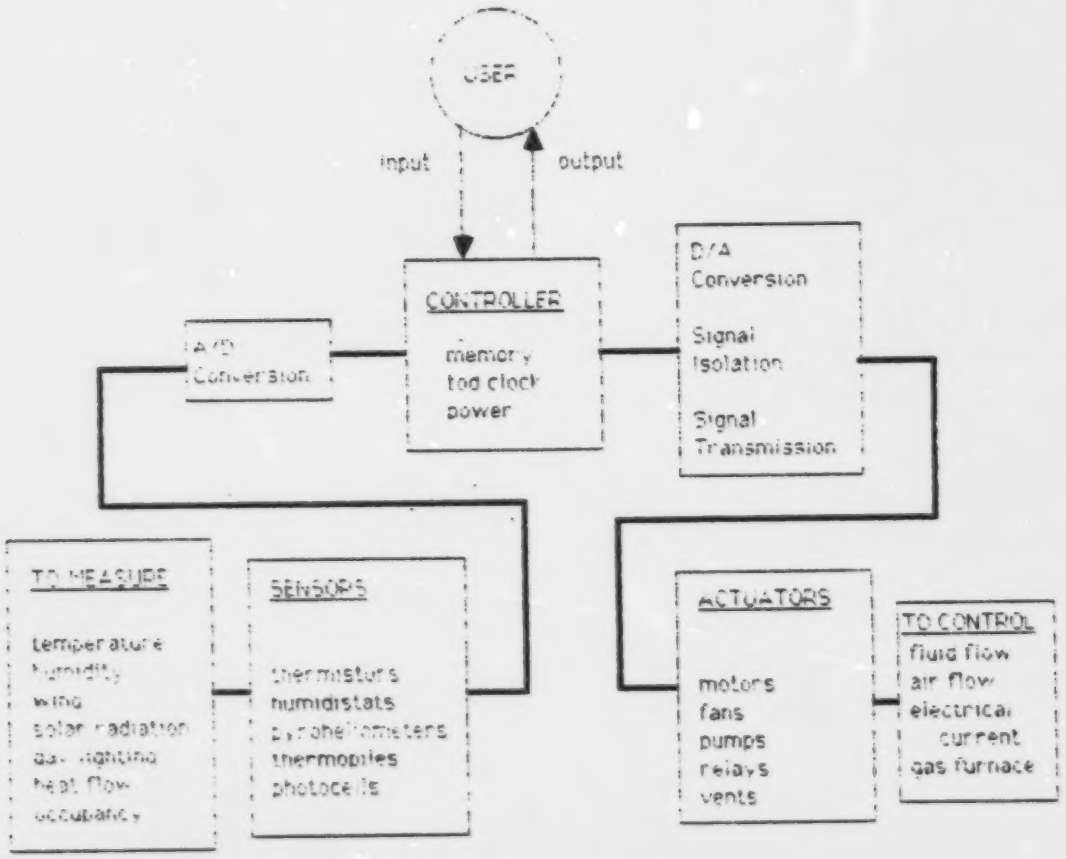

Figure 4.1 Environmental Control - A Systems Viewpoint

Sensors measure the environmental conditions, both inside and outside the building. The controller is programmed by a user (owner, installer, designer, maintainer) to switch on and off or to proportionately control the actuators based on the control logic implemented by the controller. The control logic can be implemented with relays, solid state comparators, or a microprocessor. The discussion in this section concerns microprocessor controllers since most advanced controllers use a microprocessor to implement the control logic. In the case of a microprocessor-based controller the signal is converted from an analog (voltage, current, resistance) to a digital signal understandable by a microprocessor. The microprocessor and related components (memory, real time clock, buffers, address decoders and latches, conversion units, power converter) form the "brains" of the control system. The controller interacts with the user of the system to display the time, temperature, mode, and to accept a limited subset of programming (temperature and time settings) from the user. The output section of the microprocessor-based controller usually is buffered, converted to an analog signal used to position an actuator (e.g. a relay & pump, to control air, water, etc.) based on the needs of the user (as programmed by the controller).

ZONE CONTROL

Control systems range from simple to the complex. A simple manual system, Figure 4.2a, is effective for direct user control of a condition. For example, if a person feels cold, closing the drafty window represents a manual control solution.

A single zone automatic controller (Figure 4.2b) is effective to control the comfort zone in a dwelling. There are a number of automatic thermostats available that fulfill this need.

A multi-zone system (Figure 4.2c) controls a number of separate rooms that need individual control. If each room had an automatic thermostat (e.g. a zone heater in each room controlled by a thermostat in the same room) then the user would control each thermostat independently. Since the controllers are "unaware" of each others presence in the overall control system it is difficult to implement optimal whole system strategies, e.g. setting all thermostats back at night (unless each independent zone control had a real time clock). Unless there is the capability to transfer thermal energy between the zones it is difficult to take advantage of the ability to move heat from one zone to another.

A centrally controlled system (Figure 4.2d) provides for the simplest user interaction and the most control between zones. The central controller system is popular in commercial buildings where there is a building manager and more advanced residential buildings where a controls specialist is on call. The central control system can also allow for direct user override or control at each zone.

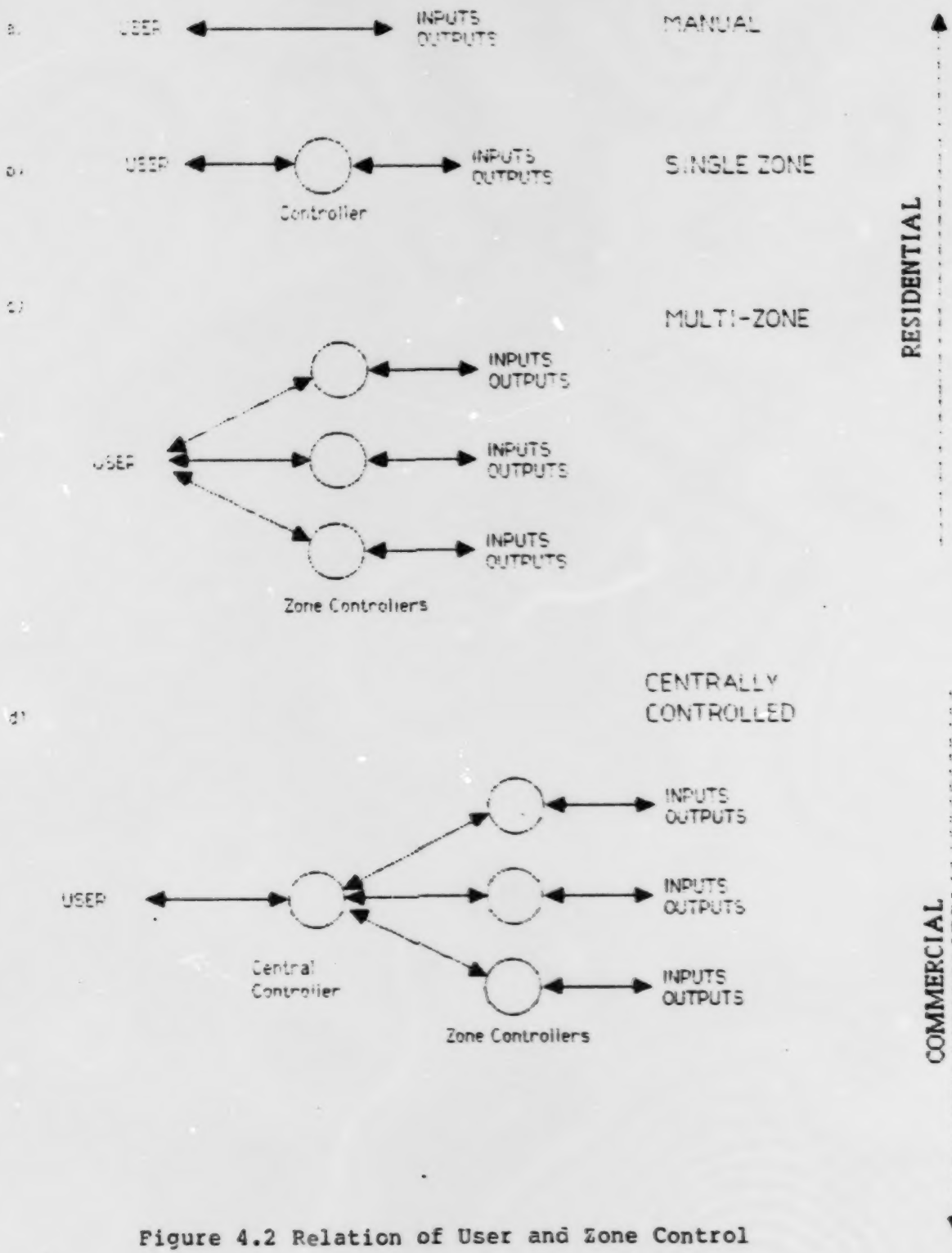

Figure 4.2 Relation of User and Zone Control

LIFE CYCLE

A change in the owner or user of a building can effect the energy performance and comfort of a building. A typical controller life cycle is illustrated in Figure 4.3. The life cycle starts with

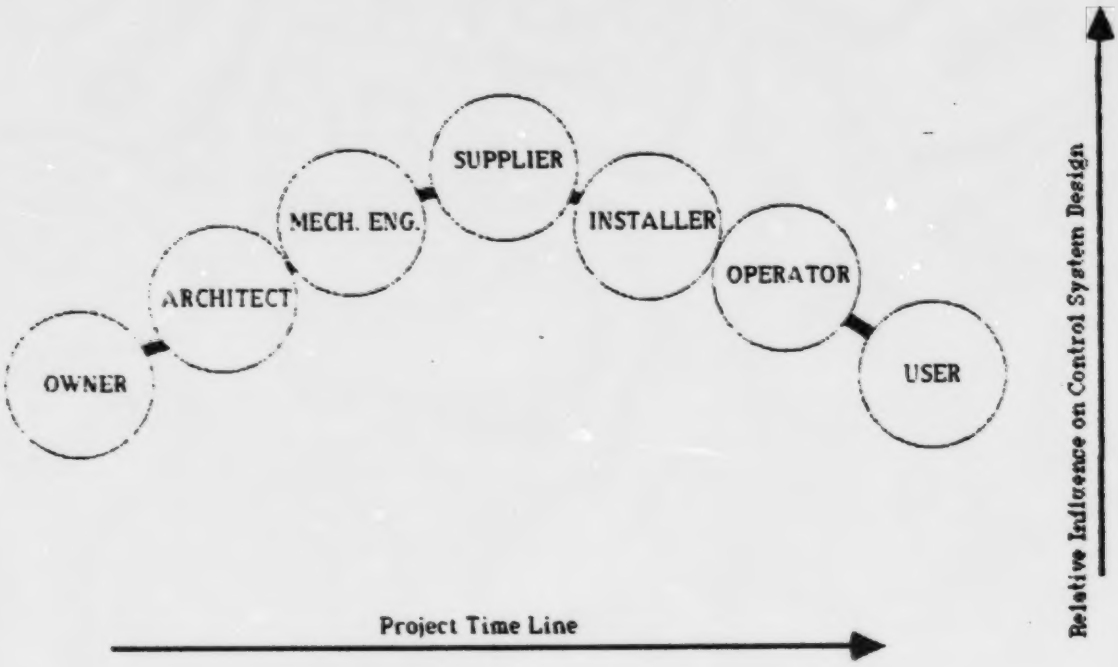

Figure 4.3 Controller System Design - Life Cycle

the building occupant/owner needs identified by a designer (architect) and referred to a consultant (mechanical/controls engineer). The consultant issues specifications pursuant to discussion with suppliers as to availability, performance, and cost. This information is approved, and the design is installed. The installer usually educates the user. All are involved during fine tuning of the system, at which time they learn how the system actually operates. At some point the user will sell or turn over the building to a new user. The new user has not had the benefit of the installation exercise. Unless the control system is extremely easy to use and self-explanatory the system will not perform as well as originally designed and the user may be uncomfortable. Solar buildings and energy systems are new (most developed in the past ten years). The second generation user of a solar building or system may not have the original dedication of the first user who did not mind manually operating movable insulation or opening the skylight when the building over heated. The new user may have different use patterns (e.g. be

away during the day when the building needs the most control in response to solar gains). The second generation user needs training on how to use the system and perhaps a different set of control system algorithms than the first generation user.

4.2 SENSORS

The controller makes its decisions based upon information collected by the sensors. If there is an error in the information collected, the controller will make inappropriate decisions. For example, if the ambient temperature sensor used to measure a freezing condition either drifts from the original value or fails, an active solar collection system can be charged with liquid at the wrong time leading to possible freezing of the liquid and consequent damage to the piping.

There are many physical phenomena that can be sensed. For solar buildings in Canada temperature is the most important. Measurements can also be made of humidity, solar radiation, electric use, heat flow, occupant behaviour, etc. The survey of designers indicated that system reliability is of primary importance. Many designers pointed to cases of failed thermistor sensors causing a loss in system performance. The problem is exasperated by a failure of controllers to sense that there is anything wrong with a sensor that drifts off value. The high limit sensor on most active systems is particularly subject to drift due to repeated thermal stressing of the sensor. Mechanical flow meters commonly fail due to particles trapped in the mechanism.

Designers indicated a need for a sensor to sense the mean radiant temperature in a room. This is particularly important for passive solar collection systems that rely on radiant thermal energy more than convection or conduction heat transfer for space conditioning. A need for remote sensors for the simple low cost single zone thermostat was indicated. Some designers felt that many sensors on solar energy systems where "fooled" by clouds passing overhead leading to poor system performance due to system cycling and incorrect system operation start and end time. Some manufacturers have even gone to using a simple 24 hour clock to turn on and off the system.

Low energy building designs place exacting demands on the HVAC and air-air heat exchange system. Good quality, inexpensive, and reliable sensors are needed to sense indoor air quality conditions and provide accurate signals to trigger the operation of ventilation equipment.

The primary energy load for commercial buildings is often the lighting load. Sensors capable of sensing natural lighting and the lighting necessary for task lighting requirements are needed. Occupant sensors are gaining popularity in commercial buildings. An ultrasonic or infrared sensor will determine if a user is in a zone and control the light accordingly. These sensors could be used in residential buildings when they become less expensive.

4.3 ACTUATORS

Actuators make things happen. Usually an electrical signal sent from the controller is used to control a mechanical component on-off or position a device between on and off (variable or step position). For the purposes of discussion we use the term actuator to refer to the actuator system including the mechanical component. For example, and actuator system (motorized valve) might include a solid state or mechanical relay, motor, linkage, valve, and assembly. Actuators in solar energy systems are used to control fluids and gases (water, air, fuel oil, natural gas, glycol mixtures) and electrical current. Devices controlled include electric hot water heaters, pumps, fans, heat pumps, boilers, movable insulation, auxiliary heaters, and radiant floor and ceiling panels.

There are also self-actuation systems. Steve Baer's (Zomeworks, Skylid) heat motor system uses a freon based system. As the sun heats up the tube containing freon, it moves the piston opening a skylid or window. Thermosiphon and bubble pump systems are self-actuating requiring no outside control system. These systems can be used on solar energy systems but have the weakness of not being able to interface to a central controller capable of optimizing a whole system.

The major problem noted with actuators is the susceptibility of mechanical parts to breakage. Actuators need to be fail safe, i.e. if power is removed, the actuator should return to an off or inert state. Providing "smart" local controllers for actuators capable of sending a "not ready" or "not working" feedback signal to the main controller can increase whole system reliability. Actuator modules could be designed to control specific solar building sub-systems, e.g. whole house fan systems, cool tubes, air-air heat exchangers, lighting systems, lawn sprinkler systems, and sunspace humidity control systems. Actuator modules could also be designed for the variety of auxiliary heating systems available which would made it easier for the homeowner/installer to integrate passive solar additions with existing HVAC technology.

4.4 SIGNAL TRANSMISSION

In most solar buildings the control system components are scattered throughout the structure, necessitating connected wires through walls, ceiling, and floors. Installing the wires and components can be expensive if professionals are used particularly for retrofit buildings. Wires can be placed before wall construction in new buildings, but the wires are still subject to failure due to dry wall nails and follow-on trade work.

A typical building wired with alternating current supplying a variety of appliances and heating systems produces an electrically noisy environment for any signal transmission system. Control systems need to overcome the building noise

inherent in the building in addition to the noise produced by its own actuators and circuits.

One common method of signal transmission is switched 24 volts alternating current (24 vac). This low voltage wiring is common to the trades along with 115 volt control currents for commercial buildings. Low voltage wiring does not require an electrician to install which lowers the cost. However, most electricians defer controls work to controls specialists which may not be cost effective in the budget of a homeowner.

Using advances in signal transmission technology can increase the signal reliability and lower the cost. One example is the wireless power line carrier system (e.g. X-10, Radio Shack "plug n' power"). The house wiring circuit is used to carry the digitally encoded control signal to the actuators. This system can be used to control a fan in a sunspace from a central controller without the need of connecting control wires to the fan. The system is moderately reliable provided that the building is a detached dwelling. If units are used in a multi-family dwelling or an apartment complex it is possible for noise or interference from other units to make the system less reliable. High frequency blocking capacitors can be used to isolate a system.

Other signal transmission systems include: coax cable, fibre optics, telephone wire, twisted pair, radio waves (low power FM). Fibre optic systems may get more popular in commercial buildings. Coax cable and twisted pair systems are gaining popularity if a network or data highway is desired. In the data highway concept blocks of digitally encoded information travel around a "data highway" on a single pair of wires. Each sensor, controller, and actuator has an address. All information is available to all components in the system. This increases the reliability. If one system is "down" another system can be programmed to perform its functions. The data highway concept also provides for monitoring of data from any point in the system.

4.5 CONTROLLER

The controller provides the system logic of the controller system. The controller responds to the sensing of physical reality, makes decisions, and sends appropriate signals to the actuators for control of physical reality.

The controller unit is the "black box" of the system. The controller receives the inputs from the sensors, makes decisions, and sends a signal to the appropriate actuator. The controller unit can be a simple set of mechanical relays, a solid state comparator circuit, or a microprocessor based unit capable of memory storage and calculations.

Designers surveyed pointed most of the blame of control system problems on the controller itself. The controller is the obvious box in the system and is usually the most expensive component.

Many designers surveyed found controllers hard to operate, training and supplier information inadequate, and information usually did not fit the application. Many found that limited control logic in the controller hampered the use in solar building applications. Dials on the controllers break, the printed circuit boards are subject to cracking and corrosion, and lack of fail safe, error checking, and diagnostic internal programs made the systems unreliable and not to be trusted. Some designers wanted controllers to be able to interface to a computer for additional control features, data monitoring, and performance evaluation. Many requested performance indicators right on the controller. Most wanted LED/LCD readouts. The controller is usually the only device that the user sees for the money he spent on the system. Many said that cost was not an issue so much as reliability (the cost/performance ratio).

Self-monitoring of installation has potential for improving controller reliability. The controller could monitor the input and outputs connected and make suggestions or provide a warning if the wrong devices are connected. Programmability by the installer is a desired feature by means of DIP switches, internal dials, changeable EPROMS, or use of EEPROMS. Almost all designers thought that the end user should not be able to change anything once the controller was installed and programmed (particularly for commercial buildings). For residential, many thought that an override or the ability to change the time and temperature program by the user was a desired feature. A performance indicator was also a desired feature with the ability to easily integrate with other control systems (particularly in commercial buildings).

There are many possible enhancements that would increase controller reliability and performance. The controller itself can be potted in a weather tight container. The use of membrane type switches on the front panel could decrease component failure. Due to decreases in the cost of computer components it is now practical to provide sophisticated software programs in the controller to:

+ monitor internal building loads, calculate parasitic power used by actuators (fans, pumps, etc.) to establish optimized operating schedules,

+ monitor electrical current used by appliances for performance evaluations and/or load shedding for peak demand metering situations,

+ telephone a local service person for repair, sound a warning signal, make a temporary program correction in the event of system malfunction,

+ be able to configure the input/output electronics to accommodate any type of sensor or actuator connected regardless of voltage, current, or operation mode,

+ estimate the building energy load parameters for the system and perform a dynamic system calculation to estimate what the performance of the system should be and note deviations from the measured performance,

+ use adaptive control algorithms, weather anticipation, and other control strategies to provide optimal control,

+ monitor the signal transmission to and from sensors and actuators and resend the signal if necessary to provide error free transmissions in the circuit,

+ implement control truth tables to assure fault free implementation of control algorithms.

4.6 HUMAN FACTORS

Many designers pointed to human factors as an underdeveloped area in controller design and application. Human factors issues in controls vary depending on the building type. Some important issues are tabulated for the residential and commercial sectors in Figure 4.4. In the residential sector the building owner, occupant, and user are usually synonymous with the exception of the developer constructed building. The developers primary concern is low cost and is typically unconcerned with user comfort and energy interests although this is changing. In the commercial sector there may be a building manager in addition to the building owner and building users who have no ownership responsibilities.

Users of residential buildings usually want systems that are simple and inexpensive. Often manual controls or independent inexpensive automatic controls will satisfy the need. The user is typically restricted to either what was installed or what is available at the hardware store in controllers (e.g. thermostats). Specialized consultants are usually not used. Larger residential building users can often justify the expense of consultants and additional controls to achieve an integrated system. There appears to be some information transfer particularly between large residential and small commercial buildings where usually there is a common contractor (electrical, mechanical, or control specialist).

The controls for new buildings are typically specified by a mechanical engineer with information from suppliers. A mechanical engineer may find it difficult to keep up-to-date with the rapidly changing specifications of commercial building controllers and may lack the up-to-date training in systems analysis, heat transfer, thermodynamics, and control theory to adequately understand the system. There is a propensity to do things the way they were done for the last job reduces of attention to the unique aspects of a particular building control

ISSUES	RESIDENTIAL	COMMERCIAL	
		OPERATOR	ZONE USER
CHOICE OF COMFORT, ENERGY, TIME CONTROL	OCCUPANT	BUILDING MANAGER	ZONE USER
DEGREE OF CONTROL	MANUAL/ AUTOMATIC	PROGRAMMING	NONE
PROGRAMMABILITY	NONE (some by installer)	FULL	NONE
MANUAL OVERRIDE	FULL OVERRIDE	FULL	NONE
MAINTENANCE	OWNER INSTALLER/ CONTRACTOR	IN/OUTSIDE CONTRACTOR	BY BUILDING OWNER
INSTALLATION	LOW BUDGET MUST BE EASY	SOPHISTICATED	NONE
$ SPENT ON AUTOMATIC CONTROLS	LOW	HIGH PAYS FOR ITSELF	NONE
INFORMATION TO MAKE DECISION	ALL	ALL	LOCAL COMFORT CONDITIONS
THERMAL LAG	MINUTES	HOURS	LESS THAN HOURS
TRAINING	SUPPLIER LITERATURE	FORMAL	NONE
# OF PEOPLE AFFECTED BY CHANGES IN CONTROL	FEW	MANY	FEW
SENSORS/ACTUATORS	INEXPENSIVE	CAN BE EXPENSIVE	ONLY FOR ZONE
APPEARANCE	AESTHETIC IN LIVING SPACE	NOT CRITICAL	NOT CRITICAL

Figure 4.4 Residential vs. Commercial Building Control Issues

project. Hence, the control system details are usually left to the suppliers who have their own interests in selling products.

One major difference in the commercial and residential markets is the investment in training on system operation. Commercial buildings either have full-time building managers or building managers on call who are trained in control systems. Residential users have to rely on the documentation that is supplied with the system which is usually too general or written for a different audience.

4.7 WHOLE SYSTEMS

The system is no more reliable than the weakest link in the system. Reliability was the number one problem of control systems cited in the survey of designers. Solar controls have to be considerably more reliable than conventional controls. For example:

1. Solar buildings often rely upon energy storage to average the energy delivered to the load. An incorrect thermistor reading or faulty controller could make the occupants uncomfortable for hours. Conversely, a forced air furnace can heat a house in a manner of minutes.

2. Failure of a control system on a liquid solar energy system could leave liquid in the pipes at the wrong time subjecting the system to freezing and consequent water damage.

3. A faulty controller on an air-air heat exchanger on a low energy passive solar building can result in inadequate air change and an unhealthy and dangerous air environment.

The control system is a system; a system of interconnected components spread through walls, ceiling, and floors. The control system is unique as a household appliance. A washing machine is one unit. It requires no connection to other units except for power and water. The controls come with the washing machine and are part of the package. If something goes wrong, you call the service person who fixes washing machines. Building environmental controls are different. The controller is most often located where the user can program it. The unit is wired to sensors and actuators scattered throughout the building. Solar energy collection systems require remote sensors and actuators not in the vicinity of a central controller. Developing a fault-tolerant, reliable, and user friendly system requires the entire package to be considered as one unit. This is rarely done. The Canadian Standards Association, for example, will test and certify the components, but the system and how it all works together is not tested. There appears to be no research or testing at the current time in the area of building control system performance and reliability. Since the entire system is difficult to test one possibility is to make the

central controller smarter. Expert system and artificial intelligence (AI) research will provide tools for control designers to make controllers easier to use and more tolerant of user error.

There is a major effort in the U.S. initiated by the National Association of Home Builders (Washington, D.C.). A consortium of manufacturers are working on a "smart" building and appliance concept, a concept that may have a major impact on building control systems. Their concept is to build microprocessor controllers into future appliances, storing the power requirements of the appliance. For example, a fan in a sunspace may require 115 volts ac, at 1 ampere. When the fan is connected a signal is sent to the central electrical panel. The precise electrical requirement is matched by the panel and supplied to the fan. It is anticipated that such a system will not only save energy but reduce fire and shock hazards in buildings.

Most controllers available for residential buildings are one zone controllers. Passive solar buildings usually perform better if the building is divided into nearly isothermal (equal temperature) zones. For example, in a single zone direct gain building the north side of the building could require heat while the south side may be too hot. Adding a small air distribution system and advanced controller could control the movement of heat from the building south side to the north zone.

Designers point to the need for whole system integration. Commercial buildings to some extent are starting to achieve this. For example, if there is a fire the HVAC system is appropriately controlled to isolate the fire zone, sound an alarm, and manage the building ventilation. Likewise with low energy and passive solar buildings it may be advantageous to consider the safety and health benefits in the development of an integrated building controller. Future controllers will likely be building controllers with solar features rather than dedicated solar controllers with single task orientation.

5.0 CONCLUSIONS & RECOMMENDATIONS

Two general observations can be drawn from the review of controllers in solar design. Specific technical recommendations follow.

First, it is important to recognize that there are basically two levels of control systems used in solar buildings. One type of control system is very simple, involving manual operation of various devices such as vents and shades by the occupants. This type of system tends to be lower cost, but does run the risk of lower energy efficiency because it is highly dependent on occupant use patterns. Most residential solar buildings rely on this type of control system. The second type of control system involves coordination of a number of solar and conventional components with the use of mechanical controls. This type of system benefits from integrated automatic controls although some devices may still be manually operated. These systems are most commonly found in commercial buildings.

The second general observation is that combined systems, active and passive, solar and conventional, are becoming more popular and more sophisticated and should be designed and controlled as an integrated whole in order to optimize energy efficiency and comfort.

Recommendations for future work on controllers to be used with solar design are presented under the following three categories: choice from the user standpoint, technology transfer, and controller design.

A. Choice of Control Systems from the User Viewpoint

1. A simple decision-making tool for designers could be developed to facilitate choice about the degree of user control wanted. A choice of inputs and outputs would determine the control strategy (see Figure 5.1). Such a tool might be combined with basic information on control options which would enable both designers and users to make more educated choices.

2. Environmental control needs to be simplified for the user. If there is a simple approach for the system and controls, use it (i.e. design natural temperature control into the building by the use of thermal storage and the ground to provide minimum/maximum temperature control). More sophisticated control systems may simplify use for the occupant but they do need to be less prone to user error. Research is needed in how advances in expert systems, e.g. systems which can determine use patterns without user input, can benefit the building control industry.

3. Cost is an issue for the user in the residential market. Less expensive controllers are needed that can perform a variety of functions for that market.

Figure 5.1 Control Requirements-Choices-Consequences

B. Technology Transfer and Information Dissemination

1. The trades need better information available about controlling solar buildings. Training programs could be developed, along the same lines as existing programs for energy conservation and photovoltaics, which provide installers and suppliers with information on basic control strategies and controller types and operation for solar buildings. A booklet could be published in conjunction with the training program which would be a relatively simple but comprehensive handbook of controls for solar. Advanced training in solar building requirements could also be developed for mechanical engineers working in the commercial controls market.

2. Controller manufacturers should be encouraged to provide installer and user-friendly documentation which provides adequate information for both installation and maintenance as well as information on how to change limits if the user is to do this. Adequate documentation would in part alleviate the problem of the "second user" where changes in the parameters for user control are needed after the system has been installed.

C. Controller Design

1. A solar option on a general building controller is needed rather than a solar controller, i.e. a controller should be a general controller capable of controlling a variety of buildings - solar buildings as a subset of those buildings. Attention should be given to the commercial market which can justify the expenditure on controls due to the consideration of payback, maintenance, and user satisfaction requirements. There are a number of areas in which specific controllers could be developed, e.g. for radiant heat panels, heat pumps, or low flow domestic hot water systems, but there are indications that the Canadian market could not support a Canadian product in these areas unless a broader market could be reached. It therefore may be more profitable to focus Canadian efforts on perfecting a general type controller for solar use.

2. Research is needed in building control algorithms. What strategies save the most energy? A controls simulator could be constructed using real control components in a building to assess whole system operation and effectiveness of proposed changes to the control system. Customized strategies for specific buildings and types of buildings are needed. The strategies should be easy to implement.

3. Work on sensors and actuators, the control system subcomponents, is indicated. Accurate and reliable sensors need to be developed to sense not only temperature, but also air quality, humidity, occupant use patterns, and appliance energy loads.

4. Solar energy systems need to be more reliable. More emphasis should be placed on the control systems in the design phase. Detailed studies of in-situ building controllers would contribute greatly to knowledge of whole system performance. Usually the solar energy delivery system is monitored without regard to controller system performance, e.g. sensor accuracy and actuator response over the life cycle of the solar energy system.

The information in this report indicates that the use of controllers is a critical element in the future of the solar building industry. It is also apparent that very few representatives of the industry are knowledgeable about potential uses for controllers and what is available. The above recommendation for training programs and a handbook of controls is thus a vital first step for future work in the area.

A second area for emphasis in future work is the development of a reliable controller capable of controlling solar buildings and the development of control algorithms. A Canadian manufactured controller with solar capabilities would alleviate some of the warranty problems presently experienced by dealers of U.S. controllers. Monitoring of the controller system performance could be used to improve controller reliability in Canadian climates. The issues of occupant comfort and energy savings are particularly important for commercial buildings and this suggests that a new product should be geared toward small commercial buildings. Such a controller would also be applicable for residential use.

Solar energy is a renewable energy resource and can be a reliable and cost effective heating source for buildings. Controls play a crucial role in the effectiveness of building energy systems. The energy efficiency of a building system can only be as efficient as the system which controls it. Research invested on building control will go a long way toward making solar energy a cost effective fuel of the future.

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APPENDIX A - BUILDING INDUSTRY SURVEY

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Name:_____ Phone: _____ Date:_____
Address:

1. Your occupation? ☐ engineer ☐ architect ☐ _____
2. Type of systems/buildings you work with?
   a) ☐ active ☐ passive ☐ _____
   b) ☐ space heat ☐ DHW heating ☐ industrial process heat
      ☐ space cool ☐ pools ☐ agricultural
      ☐ . . .

   c) Building types: ☐ single family residence ☐ multi family residence ☐ commercial

3. Are presently manufactured controllers adequate for your needs?
   ☐ No ☐ Yes . . . types that you use/specify . . .

4. What are the major shortcomings of existing controllers?
   ☐ high cost ☐ difficult to install ☐ power requirements
   ☐ limited control logic ☐ expensive to maintain ☐ difficult for user to operate
   ☐ appearance ☐ size ☐ . . .

5. In what situations are automatic controls preferable to manual controls?
   ☐ all ☐ none ☐ some
   How do you decide which is preferable?

6. What type of systems do you think will show the greatest growth in the next five years?
   ☐ space heat ☐ DHW heating ☐ industrial process heat
   ☐ space cool ☐ pools ☐ agricultural
   ☐ . . .

7. a) What features are important in selection of a controller?
   ☐ cost ☐ easy to use ☐ size
   ☐ abilility to perform specified task ☐ easy to install ☐ power requirements
   ☐ appearance ☐ easy to maintain ☐ monitoring/sensing
   ☐ . . .

   b) Which of the above features are the most important?

8. To what extent do you think the user should be able to program a controller? ?
   ☐ not at all ☐ temperature & time only ☐ change parameters ☐ algorithms

9. What do you think are the best new ideas or new directions in solar energy?

10. Where do you go for information on building control?
    ☐ consultant ☐ book ☐ supplier ☐ _____

11. Can you suggest any other people to contact for this survey?

12. Can you suggest any specific buildings which have information available on the control systems?

General comments?

Sample Survey

APPENDIX B - CONTROLLER PRODUCTS - A SAMPLE

This Appendix includes a list of manufacturers producing controllers and a product summary of the major specifications for specific controllers that are applicable to solar buildings. The products range from thermostats costing under $100 to complete building systems in the thousands of dollars.

A local supplier was contacted to get a perspective of the marketplace (what is selling). Their company sells mostly the Enerstat and White-Rodgers for residential users. The Enerstat K3WN sells for $94.50 wholesale, $151.20 suggested list and is used for the home market. The HC 7 sells for $126 wholesale / $201.60 list, includes 7 day programming, can be used with a remote sensor, displays C or F, and is popular for small commercial buildings. The HP-1 $158.20 wholesale / $253.12 retail is used for heat pump sites. The MS-1 is a multi-state thermostat with a wholesale price of $176.40 / retail of $282.24. The supplier said that specifications and brochures were difficult to get for the Enerstat series (they have been on order for over two months).

The White-Rodgers 1F90-1 sells for $103.30 with a list price of $173.01. It is common for the trades to mark up the wholesale price by a factor of two for resale to the end user.

The supplier also carries the Honeywell line but does not sell very many. One problem with the Honeywell line is that a different model thermostat is needed for many different applications (requiring a number of almost identical units to be stocked). The Honeywell T8200/A1178 sells for $104.33 wholesale (and about $200 installed). One of the major problems with the T8200 is that it only has a selection of 0,3,6, and 9 degrees C for a set-back temperature. It also has an analog temperature display. Honeywell also makes a multizone control system thermostat selling in the thousands of dollars.

Although there are a number of thermostats and controllers listed on the following pages the user/installer is usually dependent on what is available at the local supplier. In general, that selection includes single zone thermostats and single zone temperature controllers. The survey indicated that warranty return is a problem for suppliers. Almost all of the suppliers use controllers manufactured in the U.S.. It is difficult for the installer/supplier to service U.S. made equipment that needs to be cleared through customs initially, and perhaps a second and third time if there is a problem (not to mention the exchange rate, Canadian Federal sales tax, and duty).

The prices for the products on the following pages are in U.S. dollars unless stated. Most of the information came from manufacturers' literature with only U.S. prices quoted. The letters "ns" are used to denote information not stated.

CONTROLLER PRODUCTS - LIST

Clark & Co. Inc
Drawer C-1000
Underhill Vermont 05489
Tel: 802-899-2971
Model: three,see comments
Class: thermostat

Conduff Rogers
Controls Division
P.O.Box 13
Springdale AR 72765
Tel: 800-362-9223
Model: Sensor Saver
Class: building

Dupont Energy Management
Box 2543
Baton Rouge LA 70821-9990
Tel: 504 388-0801
Model: SmartStat 1500
Class: thermostat

Energy Components and Controls
2260 Northwest Parkway
Suite L
Marietta GA 30067
Tel: 404 952-5691
Model: Temp 5000
Class: thermostat

Harper-Wyman Co.
Harpco Div.
930 N. York Rd.
Hinsdale IL 60521
Tel: 312 325-3400
Model: pro-stat 5020
Class: thermostat

Heat-Timer Corp
10 Dwight Place
Fairfield N.J. 07006
Tel: 201 575 4004
Model: HPC-7
Class: building,steam heat

Heliotrope General
3733 Kenora Dr.
Spring Valley CA 92077
Tel: 619-460-3930
Model: DTT-04/94
Class: sdhw

Hoffman Controls Corp.
2463 Merrell Rd.
Dallas TX 75229
Tel: 214 243-7425
Model: Series 201 VAV
Class: zone control,commerc

Honeywell
Residential Controls Center
10400 Yellow Circle Drive
Minnetonka MN 55343
Tel:
Model: T8200
Class: thermostat

Independent Energy Inc.
P.O.Box 1305
42 Ladd St.
East Greenwich RI 02818
Tel: 401-884-6990
Model: DLX-30
Class: building

Independent Energy Inc.
Tel:
Model: CH-30
Class: sdhw

Natural Power Inc.
Francestwon Turnpike
New Boston NH 03070
Tel: 603-487-5512
Model: Series S25/26/27/28
Class: sdhw

PSG Industries Inc.
1225 Tunnel Rd.
P.O.Box 157
Perkasie Pa 18944-0157
Tel: 215 257 3621
Model: LCAE-4
Class: thermostat

Pyramid Controls
421-16N. Buchanan Circle
Pacheco CA 94553
Tel: 415-827-0160
Model: P-100
Class: sdhw

Rayflow Corp.
5015 W. Waters Ave.
Tampa FL 33614
Tel: 813 886-4412
Model: Flogarde
Class: sdhw

Robbins Engineering Inc
751 S. Richmond Rd.
Ridgecrest CA 93555
Tel: 619-375-6882
Model: Sun-seeker 1
Class: mechanical

Starbuck Data Co.
2 Mica Lane
Wellesley MA 02181
Tel: 617 237 5514
Model: SD 1232
Class: building

Sunglo Solar Ltd.
35 Citron Court
Concord Ontario L4K 2S7
Tel: 416 738-0300
Model: Pc-200 series
Class: pool control

Sunland Industries Inc.
4024 East Broadway Rd.
Suite 1081
Phoenix Arizona 85040
Tel: 602-437-1265
Model: Enerupt 2001
Class: building

Sunshine Power Co.
1918 Lancer Dr.
San Jose CA 95129-2935
Tel: 408-446-2446
Model: 800-absolute control
Class: building

Troger Enterprises
853 Apple Ave.
P.O. Box 633
Wrightwood California 92397
Tel: 619-249-5571
Model: model 14
Class: sdhw

Valera Electronics Inc.
5370 Canotek Road
Ottawa Ontario K1J 8X7
Tel: (613) 745-1257
Model: MS-1
Class: thermostat

Westcan Electrical Manufact.
Box 244
Brantford Ontario N3T 5N8
Tel: 519 759-2040

Westcan Electrical Manufacturi
Tel:
Model: SA203

Product Specifications

COMPANY: Clark & Co. Inc
ADDRESS: Drawer C-1000
Chaerhill Vermont 05489
Phone: 802-999-2971

CLASS: thermostat
MODEL: Model Name: three,see comments
Price: see comments

INPUTS: Number: one
Types: 110 and 24v
Accuracy: ns

OUTPUTS: Number: one
Rating: 110and24v
Types: heat(electric, gas oil,wood)/AC

GENERAL: Dimensions: 3x9x3 in approx
Temp. Range: ns
Mounting: ns
Power: ns
Battery: no

CIRCUIT: Processor: no
Programming: at factory
Clock: no

DISPLAY: Units: na
Type: light indicator
Finds: "comfort" status

PROGRAM: Program Time: pre-set 30 min to 12 hours
Temp: pre-set 9 or 18 deg F
Override: no
Other: no

SIGNAL: Wire:
Distribution:
Voltage:
Signal Type:

Notes: C-1 (110/220) - $120, C-2 (24v) - $126, C-4 (24v)heat/cool -$155

COMPANY: Conduff Rogers
ADDRESS: Controls Division
P.O.Box 13
Springdale AR 72765
Phone: 800-362-9223

CLASS: building
MODEL: Model Name: Sensor Saver
Price: $369

INPUTS: Number: two
Types: 10K thermistor
Accuracy: +/- 0.1 def F

OUTPUTS: Number: one
Rating: 24 vac, 1 amp
Types: HVAC system (heat and cool)

GENERAL: Dimensions: ns
Temp. Range: -60 to 200 deg F
Mounting: control unit between thermostat and the equipment, sensors in ducts
Power: 24 vac, .060 amps,1.44 watts
Battery: ns

CIRCUIT: Processor: Motorola M-6802
Programming: set at factory
Clock: no

DISPLAY: Units: deg F
Type: LED
Kinds: duct temperature

PROGRAM: Program Time: no
Temp: no
Override:
Other: 16K EPROM chip ROM

SIGNAL: Wire: ns
Distribution: ns
Voltage: 24 vac
Signal Type: on/off

Notes:

COMPANY: Dupont Energy Management
ADDRESS: Box 2543
Baton Rouge LA 70821-9996
Phone: 504 388-8801

CLASS: thermostat
MODEL: Model Name: SmartStat 1500
Price: ns

INPUTS: Number: one in, one optional
Types: solid state
Accuracy: +/- 1 F

OUTPUTS: Number: 1
Rating: ns
Types: 3 stages heat,2 stages cool,rev.valve,fan

GENERAL: Dimensions: 8.8x4.4x1.75"
Temp. Range: 40 -99F
Mounting:
Power: ns
Battery: 9volt, 4 hr min.backup

CIRCUIT: Processor: ns microprocessor
Programming: night, day, and trip programmable set points, preprogrammed
Clock: ns

DISPLAY: Units: 1
Type: numeric
Kinds: temp, 14 promptings and indicators

PROGRAM: Program Time: 7 days
Temp: 40 - 99 F
Override: economy override
Other:

SIGNAL: Wire: standard
Distribution: 100 ft.
Voltage: ns
Signal Type: ns

Notes: For both conventional and heat pump Options: economy fan control circuit, auxiliary economy control, for Coleman heat pumps, for dual speed compressor heat pumps, forced fan delay, economy override fm a remote switch, economy override mechani

COMPANY: Energy Components and Controls
ADDRESS: 2269 Northwest Parkway
Suite L
Marietta GA 30067
Phone: 404 952-5691

CLASS: thermostat
MODEL: Model Name: Temp 5000
Price: ns

INPUTS: Number:
Types:
Accuracy:

OUTPUTS: Number:
Rating:
Types:

GENERAL: Dimensions:
Temp. Range: ns
Mounting: ns
Power: ns
Battery: optional backup

CIRCUIT: Processor: ns microprocessor
Programming: ns 84 programs/week, preprogrammed
Clock: ns

DISPLAY: Units: one
Type: digital
Kinds: time, temp, day, mode of operation

PROGRAM: Program Time: 3 stages heat, 2 stages cool, 7 day
Temp: ns
Override: temporary or indefinate override
Other:

SIGNAL: Wire: standard plus one
Distribution:
Voltage:
Signal Type:

Notes: Room module plus interface, connected with three wires Temp demand duty cycling, computed recovery, programmable damper control, programmable ventilation control, program. A/C shutoff Programmable or manual operation Remote temp sensing and Key

COMPANY: Harper-Wyman Co.
ADDRESS: Harpco Div.
930 N. York Rd.
Hinsdale IL 60521
Phone: 312 325-3400

CLASS: thermostat
MODEL: Model Name: pro-stat 5020
Price:

INPUTS: Number: 1, with option of 1
Types: ns
Accuracy: +/- 1 deg F

OUTPUTS: Number: 3
Rating: 1.5 amps @ 30 volts
Types: heat, fan, and compressor relays

GENERAL: Dimensions: 2x3x7 inches
Temp. Range: 32-140 F, 10%-90% RH
Mounting: 5 ft. above floor w/ good air circ.
Power: 20-30 vac, rms 60 hz, 4.5+ amps
Battery: 9vdc not nicad

CIRCUIT: Processor: ns
Programming: preprogrammed at factory set points and time can be changed by user
Clock: y

DISPLAY: Units: only F
Type: vacuum fluorescent
Kinds: time, temp, schedule & temp. status, system on, & battery indicator

PROGRAM: Program Time: 4 times changes per day, 7 day
Temp: prog 50 - 84 F (heat), and 54 - 88 F (cool), with 2 high and 2 low set points
Override: 2 hour, constant, and vacant
Other:

SIGNAL: Wire: 18 gage bell wire
Distribution: 200 ft from t5020
Voltage: 24vac
Signal Type: on/off

Notes: if battery is low it is possible to lose the program, and range off set points is limiting for use as a sunspace/greenhouse controller. Also a T5000 electronic heat pump thermostat, T5010 commercial, and a new T5030 model with a 40-90 deg F range

COMPANY: Heat-Timer Corp
ADDRESS: 18 Dwight Place
Fairfield N.J. 07006
Phone: 201 575 4004

CLASS: building,steam heat
MODEL: Model Name: MPC-7
Price: ns

INPUTS: Number: 2
Types: solid state sensors
Accuracy: ns

OUTPUTS: Number: cycles boiler
Rating: ns
Types: ns

GENERAL: Dimensions: ns
Temp. Range: ns
Mounting: ns
Power: ns
Battery:

CIRCUIT: Processor: ns
Programming: programmable 7 days, 8 times day
Clock: realtime

DISPLAY: Units: 1
Type: LED, displays
Kinds: current status, heat system sensors

PROGRAM: Program Time:
Temp:
Override:
Other: thermal lockout prevents overheating, utilizes latent heat

SIGNAL: Wire: ns
Distribution: ns
Voltage: ns
Signal Type: ns

Notes: Also model HHR for hot water heating systems, and dhw controller with clock and manual override optional electronic optimum start that senses how long it takes to warm up a building in the morning, can control to refine heat needs to the character of the building

COMPANY: Heliotrope General
ADDRESS: 3733 Kenora Dr.
Spring Valley CA 92077
Phone: 619-460-3930

CLASS: sdhw
MODEL: Model Name: DTT-84/94
Price: $134.30

INPUTS: Number: two
Types: thermistor
Accuracy: ns

OUTPUTS: Number: one
Rating: 10 amp relay
Types: circulation pump, blower

GENERAL: Dimensions: ns
Temp. Range: ns
Mounting: ns
Power: ns
Battery: no

CIRCUIT: Processor: ns
Programming: at factory
Clock: no

DISPLAY: Units: no
Type: light indicator
Kinds: on/pumping

PROGRAM: Program Time: no
Temp: pre-set at 160 degF high limit, OFF below 80 deg F, 9/4 deg differentials
Override: no
Other: no

SIGNAL: Wire: ns
Distribution: ns
Voltage: ns
Signal Type: ns

Notes: supply a variety of solar control products The HLO-120V-30A is a heater lock-out 30 amp relay which turns off or on the power to the heating element and thermostat in an electric water heater, used with the Delta T solar controller

COMPANY: Hoffman Controls Corp.
ADDRESS: 2463 Merrell Rd.
Dallas TX 75229
Phone: 214 243-7425

CLASS: zone control,commerc
MODEL: Model Name: Series 201 VAV
Price: ns

INPUTS: Number:
Types: solid state thermist
Accuracy: 1.0 F; 0.01" WG

OUTPUTS: Number:
Rating:
Types: damper, fan

GENERAL: Dimensions:
Temp. Range: 32-140 F
Mounting: horizontal
Power: 24V AC
Battery:

CIRCUIT: Processor:
Programming:
Clock:

DISPLAY: Units:
Type:
Kinds:

PROGRAM: Program Time:
Temp: 3 stages of sequencing,
Override: damper override, can receive smoke or fire alarm signal
Other:

SIGNAL: Wire:
Distribution:
Voltage:
Signal Type:

Notes: System designed for variable air volume electronic air distrib. Includes solid state velocity sensor to control and monitor air flow; flow logic analyzer/actuator; electronic thermostat

COMPANY: Honeywell
ADDRESS: Residential Controls Center
10400 Yellow Circle Drive
Minnetonka MN 55343
Phone:

CLASS: thermostat
MODEL: Model Name: T8200
Price: approx. $200 to user

INPUTS: Number:
Types:
Accuracy:

OUTPUTS: Number:
Rating:
Types:

GENERAL: Dimensions:
Temp. Range:
Mounting:
Power:
Battery: rechargeable nicad backup

CIRCUIT: Processor: ns microprocessor
Programming: ns
Clock: digitalLCD

DISPLAY: Units: F
Type: LCD, analog
Kinds: temp, time,skip or offset mode

PROGRAM: Program Time: 7 days, two offset periods
Temp: approx. 45-85 F
Override: skip key can override next program offset period
Other: ns

SIGNAL: Wire: standard
Distribution: ns
Voltage: ns
Signal Type: ns

Notes: Also model T8085 designed for new construction with 24-volt electric clock powered by the heating system's transformer; model T8082 with quartz clock, both are electromechanical. Model T8100 is simpler programmable, no clock display or override

COMPANY: Independent Energy Inc.
ADDRESS: P.O.Box 1305
42 Ladd St.
East Greenwich RI 02818
Phone: 401-884-6990

CLASS: building
MODEL: Model Name: DLX-30
Price: $301.41

INPUTS: Number: six
Types: thermistors
Accuracy: +/- 1 deg F

OUTPUTS: Number:
Rating:
Types: spdt relays, 30 vac, 60va

GENERAL: Dimensions: 8x5x2 in approx.
Temp. Range: -27 - 227 deg F
Mounting: wall or handheld
Power: 20-30 vac, 4va max
Battery: yes, 4-aa cells for 24 hr storage

CIRCUIT: Processor: ns microprocessor
Programming: limited push-button programming by user
Clock: yes

DISPLAY: Units: F deg
Type: lcd
Kinds: time, temperature,

PROGRAM: Program Time: 3 turn-on /off timer set-points per day
Temp: differential may be set internally at 3, 5, 10, 20 F.
Override: ns
Other: data acquistion capabilities

SIGNAL: Wire: ns
Distribution: ns
Voltage: 24 vac
Signal Type: on/off

Notes: older system, limited programming capabilities, 5 year limited warranty

COMPANY: Independent Energy Inc.
ADDRESS:

Phone:

CLASS: schw
MODEL: Model Name: CH-3[illegible]
Price: ns

INPUTS: Number: 2
Types: solid state thermist
Accuracy:

OUTPUTS: Number: 1
Rating: 115VAC,1/3 HP,7.2FLA
Types: operate circulator or fan

GENERAL: Dimensions: 5 5/8x4 7/8x2 3/8"
Temp. Range: 32 - 122 F
Mounting: ns
Power: 105-130VAC, 50/60Hz, 7.4 A max.
Battery: ns

CIRCUIT: Processor: ns
Programming:
Clock:

DISPLAY: Units: 1
Type: LED
Kinds: output indicator,

PROGRAM: Program Time:
Temp:
Override:
Other:

SIGNAL: Wire: ns
Distribution: ns
Voltage:
Signal Type: on/off

Notes: Adjustable differential; recirculate freeze protection; adjust. storage high limit; test switch for troubleshooting. Plug in adaptor for connection to DLX-30 for monitoring capability.

COMPANY: Natural Power Inc.
ADDRESS: Francestwon Turnpike
New Boston NH 03070
Phone: 603-487-5512

CLASS: sdhv
MODEL: Model Name: Series S25/26/27/28
Price: S25-$225,S26-$310

INPUTS: Number: S28 - three
Types: RTD sensor
Accuracy: ns

OUTPUTS: Number: one
Rating: 10 amps resistive
Types: spst relay, pump or blower

GENERAL: Dimensions: 6x8x4 in
Temp. Range: ns
Mounting: ns
Power: 105-127 vac
Battery: no

CIRCUIT: Processor: ns
Programming: pre-set at factory
Clock: no

DISPLAY: Units: volts
Type: meter
Kinds: sensor temperature, temperature differential, output level

PROGRAM: Program Time: no
Temp: no
Override: no
Other: no

SIGNAL: Wire: ns
Distribution: ns
Voltage: ns
Signal Type: (1)

Notes: (1) proportional and on/off implemented by solid state triac

COMPANY: PSG Industries Inc.
ADDRESS: 1225 Tunnel Rd.
P.O.Box 157
Perkasie Pa 18944-0157
Phone: 215 257 3621

CLASS: thermostat
MODEL: Model Name: LCAH-4
Price: ns

INPUTS: Number: 4 preset sensors
Types: mercury sensors
Accuracy: +/- 0.5F

OUTPUTS: Number:
Rating:
Types:

GENERAL: Dimensions: 4.1x8.8x1.5"
Temp. Range:
Mounting:
Power: 24-30 volts ac,1.0 amp
Battery: CRB-2 nical rechargeable

CIRCUIT: Processor: ns
Programming: 7 day scheduling, 2 high,2 low set points can be changed by user
Clock:

DISPLAY: Units: one
Type: LCD
Kinds: time, setback staus, heating or cooling, can review schedule

PROGRAM: Program Time: 7 day , yes
Temp: replace bulbs, 35 F to 88 F
Override: no override, can be reset
Other:

SIGNAL: Wire: 24 vac standard wire
Distribution: ns
Voltage: 24 vac
Signal Type: on/off

Notes: some gas fired furnaces may need an additional interface; relay lockable cover wih special key; no temperature indicators or dials

COMPANY: Pyramid Controls
ADDRESS: 421-16N. Buchanan Circle
Pacheco CA 94553
Phone: 415-827-0160

CLASS: sdhw
MODEL: Model Name: P-100
Price: 119.50 [1]

INPUTS: Number: 4
Types: thermistors
Accuracy: ns

OUTPUTS: Number: 2,
Rating: ns
Types: pump & drain valve

GENERAL: Dimensions: ns
Temp. Range: ns
Mounting: ns
Power: believe to be 115 vac
Battery: ns

CIRCUIT: Processor: sc-310
Programming: factory fixed
Clock: no

DISPLAY: Units: no
Type: na
Kinds: operational mode, freeze,solar,power

PROGRAM: Program Time: na
Temp: no
Override: no
Other: no

SIGNAL: Wire: ns
Distribution: ns
Voltage: ns
Signal Type: ns

Notes: [1] with relays

COMPANY: Rayflow Corp.
ADDRESS: 5815 N. Waters Ave.
Tampa FL 33614
Phone: 813 886-4412

CLASS: schw
MODEL: Model Name: Flogaroe
Price: $278

INPUTS: Number: 2
Types: mil spec thermistors
Accuracy: ns (within 4 F dif)

OUTPUTS: Number: 1
Rating: ns
Types: circulating pump

GENERAL: Dimensions: ns
Temp. Range: max 200 F continuous
Mounting: pv display plus controls and motorized dual 3-way valve
Power: 6 volt DC motor 90 MA
Battery: rechargeable lead acid battery

CIRCUIT: Processor: ns
Programming:
Clock:

DISPLAY: Units: ns
Type:
Kinds: trouble lights and alarm buzzer

PROGRAM: Program Time: ns
Temp:
Override:
Other:

SIGNAL: Wire:
Distribution:
Voltage:
Signal Type:

Notes: automatic freeze protection; dual automatic freeze protection as option using remote thermostat; overheat protection; battery backup; alarm buzzer signals battery replacement required
Includes controller, motorized valve, tank sensor collector

COMPANY: Robbins Engineering Inc
ADDRESS: 751 S. Richmond Rd.
Ridgecrest CA 93555
Phone: 619-375-6882

CLASS: mechanical
MODEL: Model Name: Sun-seeker 1
Price:

INPUTS: Number:
Types:
Accuracy:

OUTPUTS: Number:
Rating:
Types:

GENERAL: Dimensions:
Temp. Range:
Mounting:
Power:
Battery:

CIRCUIT: Processor:
Programming:
Clock:

DISPLAY: Units:
Type:
Kinds:

PROGRAM: Program Time:
Temp:
Override:
Other:

SIGNAL: Wire:
Distribution:
Voltage:
Signal Type:

Notes: provides sun-tracking for collectors and arrays,consists of a pair of cylindrical tubes each of which is connected by means of flexible hydraulic hose to opposite ends of a double-acting hydraulic actuator

COMPANY: Starbuck Data Co.
ADDRESS: 2 Mica Lane
Wellesley MA 02181
Phone: 617 237 5514

CLASS: building
MODEL: Model Name: SD 1232
Price: $690 + 53

INPUTS: Number: 8 analog + 8 digital
Types: analog -4 to +4volts
Accuracy: +/- 1mV [1]

OUTPUTS: Number: 8 optosiolated digit
Rating: 1500 V, 50 mA
Types: digital

GENERAL: Dimensions: 11x9x2, alum case
Temp. Range: ns
Mounting:
Power: 9 volts dc @ 500 mA (included)
Battery:

CIRCUIT: Processor: Motorola 6802,2k rom
Programming: 4k ram, fully prog. and usable as data logger, opt. soft. avail
Clock: real time

DISPLAY: Units: host compu
Type: host
Kinds: host computer

PROGRAM: Program Time: host computer
Temp: host computer
Override: host computer
Other: host computer

SIGNAL: Wire: rs-232
Distribution: 7'
Voltage:
Signal Type:

Notes: [1] Digital inputs: TTL compatible, 0.3 V hysteresis, protected to +/- 200 volts mainly for data acquisition, must be used with a computer,another model sd8232 for data acquisition, no real time clock; all communications are polled

COMPANY: Sunglo Solar Ltd.
ADDRESS: 35 Citron Court
Concord Ontario L4K 2S7
Phone: 416 738-0300

CLASS: pool control
MODEL: Model Name: Pc-200 series
Price: ns

INPUTS: Number: 2
Types: ns
Accuracy: ns

OUTPUTS: Number:
Rating:
Types:

GENERAL: Dimensions: ns
Temp. Range:
Mounting: ns
Power: 12 volt AC motor
Battery: ns

CIRCUIT: Processor: ns
Programming:
Clock:

DISPLAY: Units: 1
Type: Led
Kinds: flashing Led indicates pool temp, fault light for sensors

PROGRAM: Program Time:
Temp:
Override:
Other:

SIGNAL: Wire: two conductor #18
Distribution:
Voltage:
Signal Type:

Notes: Frost protection;

COMPANY: Sunland Industries Inc.
ADDRESS: 4024 East Broadway Rd.
Suite 1001
Phoenix Arizona 85040
Phone: 602-437-1265

CLASS: building
MODEL: Model Name: Enerupt 2001
Price: $175

INPUTS: Number: one
Types: ns
Accuracy: ns

OUTPUTS: Number: one
Rating: ns
Types: ns

GENERAL: Dimensions: 8x4x2 in
Temp. Range: ns
Mounting: ns
Power: 24 vac +/- 10%, 60 Hz
Battery: yes

CIRCUIT: Processor: ns
Programming: at factory, user has limited options
Clock: yes

DISPLAY: Units: F
Type: led
Kinds: time, temperature

PROGRAM: Program Time: yes
Temp: four programmable temperature levels
Override: yes
Other: ns

SIGNAL: Wire: ns
Distribution: ns
Voltage: ns
Signal Type: ns

Notes: has algorithms for heat pumps/compressors

COMPANY: Sunshine Power Co.
ADDRESS:
1018 Lancer Dr.
San Jose CA 95129-2935
Phone: 408-446-2446

CLASS: building
MODEL: Model Name: 800-absolute control
Price: $595

INPUTS: Number: eight
Types: assume thermistors
Accuracy: .9-2.7 deg F

OUTPUTS: Number: eight
Rating: 10 amps at 120vac
Types: spdt relays

GENERAL: Dimensions: 18x18x4 in
Temp. Range: 32-104 deg F.
Mounting: basement
Power: assume 120vac
Battery: no

CIRCUIT: Processor: ns
Programming: comparator logic
Clock: no

DISPLAY: Units: C or F deg
Type: led
Kinds: temperature

PROGRAM: Program Time: no
Temp: differentials and set-points programmable
Override: no
Other: hardwire jumper for mixing and matching inputs

SIGNAL: Wire: ns
Distribution: ns
Voltage: ns
Signal Type: ns

Notes: master unit large in size,no clock, space to write in input and outputs,in summary is a flexible comparator type programmable controller requires a fairly sophisticated user

COMPANY: Troger Enterprises
ADDRESS: 853 Apple Ave.
P.O. Box 633
Wrightwood California 92397
Phone: 619-249-5571

CLASS: sdhw
MODEL: Model Name: model 14
Price: $55.75

INPUTS: Number: one
Types: phototransistor
Accuracy: ns

OUTPUTS: Number: one
Rating: 115 vac, 60 hz, 4a
Types: pump, or fan

GENERAL: Dimensions: 3x6x3 inches approx
Temp. Range: control box 0-135 deg F, sensor -40-150 deg F
Mounting: control box near pump and storage tank, PV sensor on coll. array
Power: 115 vac +/- 15%, 60 hz
Battery: ns,

CIRCUIT: Processor:
Programming: ns
Clock: no

DISPLAY: Units: amps
Type: led
Kinds: relay coil current

PROGRAM: Program Time: no
Temp:
Override:
Other: select the solar radiation level at 100,200,300 watts

SIGNAL: Wire: 18 gauge bell wire
Distribution: ns
Voltage: 24
Signal Type: on/off

Notes: unique type of controller

COMPANY: Valera Electronics Inc.
ADDRESS: 5370 Canotek Road
Ottawa Ontario K1J 8X7
Phone: (613) 745-1257

CLASS: thermostat
MODEL: Model Name: MS-1
Price: $282.24 sug. list

INPUTS: Number: 1
Types: in unit
Accuracy: .25 C

OUTPUTS: Number: 1, 2 stages
Rating: us
Types: also models for Heat Pumps

GENERAL: Dimensions: 165mmx95mmx38mm
Temp. Range: 0 C to 55 C
Mounting:
Power: 15-30 vac, .05-1.5 amps, + up to 4.0 amp
Battery: 9v dc for storage

CIRCUIT: Processor: ns
Programming: switches
Clock: internal

DISPLAY: Units: C or F
Type: LCD
Kinds: Time, Temp, Mode, Stage, Day of Week

PROGRAM: Program Time: Yes
Temp: Yes
Override: Yes
Other: 7 day programming

SIGNAL: Wire: typ. thermostat wire
Distribution: ns
Voltage: 24 vac
Signal Type: on/off

Notes: K3-A and K4-W no longer made no info available on EC7 (new model) priced at 202 sug. list, can use a remote sensor, display C or F, 7 day programming Other Models: K3WN $151.20 list, HP-1 $253 list (for heat pumps) all prices in CDN $.

COMPANY: Westcan Electrical Manufact.
ADDRESS: Box 244
Brantford Ontario N3T 5M8
Phone: 519 759-2040

CLASS: thermostat-line volt
MODEL: Model Name: TS101 and TD102
Price: approx. $20 cnd

INPUTS: Number:
Types: proportioned bimetal
Accuracy: 1/2 C

OUTPUTS: Number:
Rating:
Types:

GENERAL: Dimensions:
Temp. Range: 10 - 32 C
Mounting: standard vertical switch box
Power:
Battery: ns

CIRCUIT: Processor:
Programming:
Clock:

DISPLAY: Units: analog
Type:
Kinds: temp

PROGRAM: Program Time: night setback option
Temp:
Override:
Other:

SIGNAL: Wire: standard 75 C
Distribution:
Voltage: csa 22 amp
Signal Type: line volta

Notes: Single line break and double line break models.

COMPANY: Westcan Electrical Manufacturi
ADDRESS:

Phone:

CLASS: thermostat
MODEL: Model Name: SA203
Price: approx. $350 cnd

INPUTS: Number:
Types:
Accuracy:

OUTPUTS: Number:
Rating:
Types:

GENERAL: Dimensions:
Temp. Range: ns
Mounting: ns
Power: one VA per controlled thermostat, 10VA
Battery:

CIRCUIT: Processor: ns microprocessor
Programming: preprogrammed, user programmable
Clock:

DISPLAY: Units: 1
Type: digital
Kinds: time

PROGRAM: Program Time: 7 day clock, 2 setbacks,2 forward per day
Temp:
Override: manual override
Other:

SIGNAL: Wire: class II low voltage
Distribution:
Voltage: 24 VAC
Signal Type:

Notes: Mainly programmable night set back controller. interface relay allows model to be used for programmed setback of lighting systems, air handling systems, heating/cooling systems. Designed for electric baseboard heating system, zonal heating.

COMPANY: White-Rodgers
ADDRESS:
Markham Ontario
Phone:

CLASS: thermostat
MODEL: Model Name: 1F90-1
Price: $ 173 suc. list CDN

INPUTS: Number:
Types:
Accuracy:

OUTPUTS: Number:
Rating:
Types:

GENERAL: Dimensions:
Temp. Range:
Mounting:
Power:
Battery:

CIRCUIT: Processor: pre-programmed
Programming:
Clock:

DISPLAY: Units: LCD
Type: LCD
Kinds: time, temp, temp setting, time period programmed when programming

PROGRAM: Program Time: pre-programmed, can set 4 settings/day, 2 sep. schedules stored
Temp:
Override: manual override to set constant temp
Other:

SIGNAL: Wire:
Distribution:
Voltage:
Signal Type:

Notes: